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ABOUT ELECTRO-MAGNETIC WIRE-ROPE TESTING IN NEW BRUNSWICK MINES AND RELATED DATA

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ABOUT ELECTRO-MAGNETIC WIRE-ROPE TESTING IN NEW BRUNSWICK MINES AND RELATED DATA

by

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ABSTRACT

Responding to a request expressed by both the Canadian mining industry and its regulatory authorities, the Mining Research Laboratories (MRL) of CANMET, Energy, Mines & Resources Canada, undertook a research program with the following objectives: (a) to establish, and analyse, the comparative level of accuracy achieved by a range of commercially available electro-magnetic (EM) mine-shaft wire-rope testers, (b) to examine, and comment upon, the diverse demands placed upon these non-destructive test (NDT) examinations by the various regulatory authorities, and (c) to examine, and analyse, the problems inherent in current instrument and operator certification practices.

MRL undertook this ambitious program on both an in-house, and a contracted, basis; the latter being funded by the Canada/New Brunswick Mineral Development Agreement. Within the mandate of its in-house work, MRL investigated, and analysed, the test-results contained in the uniquely extensive data-bank established during the past three decades by the Rope Testing Laboratory of the Ontario Ministry of Labour, as well as data from many other Canadian and US sources.

The results of this work are available in two previous MRL reports (numbers 88-78 and 89-14), and now in this report. These include detailed information about: (1) the actual test-results obtained with three Canadian designed and built EM instruments (the Rotesco AC, the Rotescograph, and the Magnograph) on mine-shaft wire-ropes, (2) the ropes thus examined, and (3) the regulatory requirements governing these tests.

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Conclusions relative to all three of the above quoted research objectives have been drawn.

The conclusions are based upon the final product produced by the NDT instrument operators, i.e., upon the estimates of actual loss-of-breaking-strength (LBS). In other words, upon the results achieved by the entire NDT testing cum calculatory process. This process involves: (a) the EM instruments, (b) the operators, and (c) the regulations governing the process.

The results from the contracted work are covered only marginally in the present report. These will be published in forthcoming reports. In these reports attention will be focused upon details of the basic physical characteristics of the EM instruments themselves (three Canadian, one American and one, or two, European), and upon such questions as to how these characteristics influence test results and user preferences.

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BACKGROUND

It is generally accepted that present day, commercially available, electro-magnetic (EM) type wire-rope test instruments have played an important role in making mine-shaft hoisting operations much safer than these were before. It is, however, also well known that the accuracy of rope strength loss estimates, based upon these EM measurements, still leaves much to be desired. Consequently, the New Brunswick mining industry and regulatory authorities have unanimously endorsed the need for undertaking an in-depth evaluation of a representative range of presently available EM testers, on a carefully controlled comparative basis.

After preparatory work at CANMET's Mining Research Laboratories (MRL), contracted work was commenced in July, 1988. It is being funded from Canada/New Brunswick Mineral Development Agreement (MDA) sources. Full details of the effort to be undertaken within the framework of this contract are contained in the relevant "Work Statement", published elsewhere (1). The results will be published in 1990, in a final contract-report. In the meantime, however, two CANMET reports (1, 2) have already been published as a result of the extensive in-house efforts by MRL; undertaken to properly quantify the need for the work in question. These were, to a large extent, based upon the unique and extensive data-bank accumulated during the past several decades by the Rope Testing Laboratory of the Ontario Ministry of Labour (MOL).

The present report is based on additional data. It further broadens the basis, and thereby the validity of the conclusions reached in the previous CANMET reports. Moreover, in this report special importance is attached to test data obtained from New Brunswick sources.

INTRODUCTION

The present report is structured in accordance with the major areas of interest identified by the "Objectives" of the Canada/New Brunswick MDA supported contract previously mentioned. In particular, we are examining: (a) the level of accuracy — with special regard to the regulatory rope removal criteria — with which EM instrument-based Loss of Breaking Strength (LBS) estimates are currently being made, and (b) the most likely reasons for the known inaccuracies of estimation, be these of instrument, operator, or regulatory origin.

We also take particular note of the principal conclusions established by the authors of the previous CANMET reports (1, 2), notably:

(a) that, at the time of removal, a considerable number of mine-shaft ropes had actually lost much more of their original breaking-strength than had been estimated on the basis of EM testing;

(b) that, in a number of cases, this loss considerably exceeded the limit permitted by the regulatory authorities;

(c) that a large number of the EM instrument-based LBS estimates did not lie within the desired ±4% accuracy range established by Ontario's Performance Requirements;

(d) that there appears to be sufficient evidence to indicate that "official" EM testing should not be restricted to just a single instrument "approved" by the authorities. The principle of instrument approval itself might warrant further consideration;

(e) that, on the whole, the EM instrument-based LBS estimates are no better, or worse, whether obtained by mine operators, by service companies, by research organizations, or by the instrument makers themselves, as long as the operators have a thorough understanding of: (1) the procedures to be followed, (2) the technical and operational background of the ropes being tested, as well as (3) the basic physical characteristics of the instruments they are using. Consequently, the regulatory problem of operator "competency" and of their "certification" also warrants renewed consideration;

(f) that certain rope constructions (e.g., for spin-resistance) and certain rope defects (e.g., corrosion and those related to work-hardening) involve particularly difficult-to-quantify rope deterioration phenomena. Moreover, in the case of Locked Coil ropes, there is a conspicuously large number of data-pairs with negative "true" LBS values, and with NDT=0% measurements;

(g) that government regulations, even across Canada itself, involve a very wide variety of stipulations. It might be advisable to study further the underlying reasons for, and the implications of, this situation;

(h) that many rope failures occurred, despite routine EM testing of subject ropes in accordance with statutory requirements;

(i) that better information exchange within the mine-shaft hoisting fraternity, both in industry and regulatory circles, would be mutually beneficial;

(j) that presently extant EM wire-rope test-instrument approvals (1) seem to be limited to stranded rope constructions, and (2) are outdated;

(k) that Loss of Metallic Area (LMA) based (rather than LBS based) rope removal estimates are, on occasion, also of questionable accuracy. Consequently, both hardware-related and human factors need to be of concern when comparing the performance of the EM rope testers in question.

All of the foregoing conclusions are of immediate concern to the New Brunswick mines and authorities — with the possible exception of the in-house NDT testing with mine owned instruments (point e.) because this is not being practised in New Brunswick at present. In this report we reexamine the above conclusions, with special reference to New Brunswick related data.

ACCURACY OF EM TESTER BASED LBS ESTIMATES

A large number of test results was published in the two previous CANMET reports (1, 2). These data were obtained at the Rope Testing Laboratory of Ontario's Ministry of Labour, Mining Health and Safety Branch, using three Canadian designed and built instruments. Only non-destructive test (NDT) results involving one particular (usually the "worst") rope segment were analysed by the authors of the previous reports. The distributions of errors of estimation were illustrated by means of histograms, and the detailed test results summarized in Tables and Figures. Moreover, a statistical analysis was prepared of the likely "acceptability" (within the terms of Ontario's Performance Requirements) of future random test results.

In this report we publish a number of additional test data (see Tables 1, 2, and 3 in Appendix). The use of an American EM tester is now also involved. Further, these data include NDT results obtained with other than merely the "worst" rope samples because we are now also concerned with the comparative, rather than only the absolute, accuracy of the various EM testers.

Consequently, from all the data tabulated both in the previous (1) and present reports, we selectively present (see Figures 1, 2, and 3 in Appendix) only those data-clusters that involve measurements on the same rope-length with more than just a single EM instrument. We do not restrict ourselves to comparative test-results emanating from New Brunswick sources alone because of their limited number (only five for the Locked-coil ropes, one for the Non-rotating ropes, and four for the Stranded ropes). We could not, therefore, base our general conclusions on this small sample. We do, however, examine the New Brunswick test-results with special care in the light of our overall conclusions.

As in the previous reports (1, 2) we use three sub-divisions based on rope construction — i.e., LC for Locked Coil; NR for Non Rotating (or Spin Resistant) and STR for Stranded rope constructions. Additional information about the ropes used, and the range of tests performed on them, can be obtained from Ontario Ministry of Labour test numbers quoted.

In Figures 1, 2, and 3 the congruent data clusters, obtained by using several EM instruments along the same wire-rope lengths, are assembled along horizontal lines (some of these are shown as broken lines, to better illustrate this point). The "true", i.e., destructively-obtained LBS value of each cluster, is located on the 45 deg line in the Figures. The distance of each NDT data point from the "true" value is a measure of the accuracy of the estimate in question, i.e., of the error of estimation. As in the previous reports (1, 2):

$$\text{Error, \%} = (\text{DT, \%} - \text{NDT, \%})$$

Both DT and NDT refer to %LBS, the former being obtained by destructive testing, and the latter non-destructively estimated. A positive LBS means a reduction of the original breaking strength; a negative one means a gain. Moreover, a positive error means that the EM instrument operator overestimated the actual LBS, while a negative error reflects an underestimate of the "true" LBS. In accordance with Ontario's Performance Requirements (1) only an error range of $\pm 4\%$ is "acceptable". Table 4 illustrates the scatter between the results obtained by the different operators, using their individual techniques for calculating the LBS values from the LF and LMA chart-traces of their respective instruments. Table 4 is based on all the data-pairs published thus far, including the previous (1, 2) and the present ones.

For illustrative purposes, not only the $\pm 4\%$ estimating error lines — which enclose the "acceptable" range of data points — but also the $\pm 6\%$ ones are shown in Figures 1, 2, and 3. Moreover, to clarify the clutter of points that occurs in certain data-ranges, sections of Figure 1 (see Figures 1a, 1b, and 1c in Appendix) and of Figure 3 (see Figure 3a in Appendix) have been enlarged by subdividing them into several ranges.

Histograms have not been prepared for this report. The ones given in the previous reports (1, 2) adequately illustrate the standard bell-curve type of distribution of the errors of estimation. Moreover, two important parameters, namely the Mean Value of the data ($\overline{X}$) and their Standard Deviation (S), are included in Table 4. In addition, a grouping of all the available data points, both given previously (1, 2) and presently, has been presented in Tables 5, 6, and 7 (see Appendix). The main objectives of our data-grouping are to determine: (a) how many of the data-points lie in the $<10\%$ range, and how many in the $\geq 10\%$ destructive, i.e., "true" LBS range, and (b) how many of the results within each of these categories are "acceptable" on the basis of Ontario's Performance Requirements, and how many are not.

Our tabulation is presented separately for each of the four EM instruments investigated, as well as for each of the three rope-constructions considered. We chose

Table 4

Summary Analysis of All Test Data

EM instr. used — results obtained	Rope construction		
	LC	NR	STR
Rotesco AC —			
total # of DT/NDT data-pairs, Σ	113	31	144
$\overline{X}$ of all errors, %	-0.72	-16.0	-6.5
S of all errors, %	8.1	16.9	11.2
"acceptable" data**, % of Σ	37	33	38
Rotescograph —			
total # of DT/NDT data-pairs, Σ	51	1	34
$\overline{X}$ of all errors, %	1.1	—	0.10
S of all errors, %	4.0	—	8.0
"acceptable" data**, % of Σ	65	0	56
Magnograph —			
total # of DT/NDT data-pairs, Σ	69	6	26
$\overline{X}$ of all errors, %	0.83	-3.3	0.23
S of all errors, %	4.8	6.9	10.0
"acceptable" data**, % of Σ	64	83	50
NDT Technologies — LMA 250			
total # of DT/NDT data-pairs, Σ	8	—	—
$\overline{X}$ of all errors, %	4.6	—	—
S of all errors, %	6.0	—	—
"acceptable" data**, % of Σ	25	—	—

**: % of total NDT data — i.e., of "estimated" strength-losses — that are within the "permissible" (in the sense of Ontario's Performance Requirements) $\pm$4% error range; the NDT=0 values are omitted here, and considered elsewhere.

these categories in view of the overall project objectives previously referred to in the *Introduction*.

From the Figures and Tables in this report we note:

In case of the LC ropes:

(a) that the majority of the NDT measurements, with any one of the four EM instruments used, was obtained on rope samples whose "true" LBS values are in the <10% DT range. This is reassuring from a safety point of view;

(b) that a majority of all the NDT data is an overestimate of the "true" LBS value, and that most of these overestimates occur in the <10% DT range. Again, this is reassuring from a safety point of view, but not so satisfactory from a competitive (i.e., operational cost) point of view;

(c) that, of the data in the <10% range, only some 48% to 68% are in the "acceptable" error range. This is not satisfactory on the basis of Ontario's Performance Requirements;

(d) that many (some 8% to 42%) NDT measurements were obtained on rope samples whose "true" LBS values are in the ≥10% DT range. In fact, some of the DT values are even in the order of 30% LBS, and others in the 15% to 23% LBS range. This could lead to dangerous situations;

(e) that a significant number of the measurements resulted in NDT=0% estimates, with corresponding "work hardened" DT results. This fact must be remembered when estimating the operational life of LC ropes on the basis of EM measurements.

In case of NR ropes:

(a) that only a relatively small number of data-pairs is available for this type of rope construction. Consequently, our conclusions are of relatively little significance, in statistical terms;

(b) that the majority of the NDT measurements, with any of the three EM instruments used, was obtained on rope samples whose "true" LBS values are in the ≥10% DT range. Some of these DT values are in the 30% to 40% LBS range, with the occasional one even in the order of 60%. This can lead to very dangerous situations;

(c) that with the Rotesco AC tester (the only one with more than a minimal number of test results) the majority of LBS estimates are "acceptable" in the <10% DT range, but not so in the ≥10% DT range;

(d) that with the Rotesco AC tester, the majority of test-results underestimate the "true" LBS, an "advantage" from a competitive, but not from a safety point of view.

Table 8 (after ref. 1)

Summary Listing of Mine-shaft Ropes

In the Province of	Total # reviewed	Of total:		
		LC (%)	NR (%)	STR (%)
New Brunswick	95	69	13	18
Ontario	479	26	20	54
Saskatchewan	254	77	21	2
Manitoba	85	20	24	56
Quebec	38	21	5	74
Nova Scotia	14	—	7	93
British Columbia	16	—	—	100

In case of STR ropes:

(a) that, contrary to the situation in case of the LC ropes, the majority of the NDT measurements, with any of the three EM testers used, was obtained on rope samples whose 'true" LBS values are in the $\geq$10% DT range. This is an "advantage" from a competitive, but not from a safety point of view. Some of the DT values are in the 20% to 30% LBS range, with the odd one even in the order of 40%, or more. This can lead to dangerous situations;

(b) that of the data in the $\geq$10% DT range only some 28% to 47% are in the "acceptable" error range;

(c) that with the Rotesco AC instrument most NDT data are underestimates of the "true" LBS; with the other instruments there is a fairly even distribution between over and underestimates.

Having analysed the test results according to three different rope constructions, the question arises whether all of these are, in fact, actually used in New Brunswick as they are elsewhere in Canada. In other words: are our conclusions of equal importance to the mining industry in New Brunswick, as they are elsewhere? The answer is: yes, as may be seen from the data listed in Table 8.

ACCURACY OF EM TESTER BASED LMA ESTIMATES

From the foregoing we conclude that the non-destructively obtained and LBS based mine-shaft wire-rope removal criterion — which is included, as an example, in New Brunswick's and Ontario's Mining Regulations — is not being met, as far as Ontario's Performance Requirements for EM Mine Shaft Rope Testing Devices is concerned. These requirements are, however, written into the regulations.

It is a fact that in some of the other Canadian provinces, as well as in foreign countries, removal criteria do not include non-destructively obtained and LBS based values (1). At the meetings of the ASTM Committee E-7 on non-destructive testing (E07.07.10, Wire-rope Applications) it was decided that LBS based rope-removal criteria should not be among the problems discussed. For the reasons listed below we disagree with this:

(a) many mine regulations involve rope-removal criteria that are based on LBS estimates, obtained with the use of EM instruments. This can not be ignored;

(b) while we are well aware of the serious problems involved in converting the LMA and LF chart-parameters into LBS values, we do not, without substantial proof, consider this to be an insurmountable problem;

(c) in Canada instrument operators are willing to provide the required LBS estimates, and have done so for many years. No details have been published so far about the exact algorithm involved in doing this, but we suggest that the onus of disproving the legitimacy of the procedures rests with those who question them.

We are not able, at this point, to present a method for improving on current techniques for obtaining EM instrument-based LBS estimates. We can, however, present data on the proposed alternative method, namely the desire to base rope removal criteria on the LMA (plus LF) traces of the EM instruments, rather than on the LBS based estimates.

As to the EM instruments' ability to detect local faults (LF), excellent comparative data were published elsewhere, in 1978 (3, 4). Unfortunately, it is much more difficult to obtain accurate comparisons between the "true" LMA values that obtain in operational mine-shaft ropes and the equivalent EM instrument based estimates, than it is to do the same for the LBS data-pairs. For this reason, and because most Canadian rope removal criteria are actually based on LBS rather than on LMA, there is no Canadian data-bank on comparative LMA tests, as there is on comparative LBS results.

We are aware of a limited number of field data (as opposed to laboratory ones); examples are those from the US (5, 6) and from the Federal Republic of Germany (7). At this time, however, we choose to refer only to our own results, achieved during CANMET's contracted work (see Table 9 in Appendix). Verification of these data, and an explanation of the occasional conspicuous scatter, will have to await publication of the final contract report. Even so a comparison of the results is most instructive. It appears that occasional errors are of human origin, due to the pressure of circumstances, and are not due to shortcomings of the hardware.

In other words: one cannot contend that a rope removal criterion, involving EM instrument-based LMA values, is ipso facto always more reliable than an LBS-based one. The end-product involves many other factors, besides hardware related ones, such as training, prior experience, on site conditions (both present and past), rope construction related influences, as well as regulatory, certification, and similar aspects.

ROPE FAILURES, NEAR FAILURES, AND OTHER OCCURRENCES OF SPECIAL INTEREST

As noted earlier in our report, rope failures continue to occur. This is despite the fact that the failing ropes had been routinely tested on a mandatory basis, and had been considered to be fit for further service. Elsewhere (2), a listing was published of the EM instrument-based LBS estimates that applied to these occasions. It illustrated the misleading nature of these LBS data. As noted in the article referenced, failures were due to the uncertainties inherent in the currently practised LBS evaluation system as a whole, and not necessarily due to any shortcomings of the instruments *per se*.

An in depth evaluation of each occurrence could not be given in the earlier publication. We are, therefore, re-examining rope failures that are of special interest in this report. Most of these happened in New Brunswick mines. Others are discussed because, although these occurred in Ontario, (a) they involve a companion rope of the one that failed in New Brunswick, and (b) they round off the relevant rope sizes and constructions that are available from New Brunswick sources.

Case (a)

Brunswick Mining & Smelting Corp. Ltd., Bathurst, N.B.

$2\frac{1}{8}$ in. nominal rope diam., 6 × 7 construction (6 outers @ .237-.238 in., and 1 centre @ .247 in.)

#3 Shaft; South Skip; T.R.#1; Reel # 010343

Installed: 11/6/82; Failed: 4/2/86 (after 44 months of service) about 105 ft below the counterweight (c/w).

The rope was tested on 9/11/82; 5/3/83; 31/8/83; 18/2/84; 19/6/84; 9/9/84; 1/3/85; 7/5/85; 5/10/85; and 13/1/86, often not only with the Rotesco AC, but also with the Rotescograph instrument.

Negligible LBS (2.5% max) was reported along the rope section that failed ultimately, up to, and including, the 31/8/83 testing. A cautionary note regarding the need for visual examination 95 ft below the c/w was, however, included in the latter test report. The estimated LBS in the critical rope section suddenly, and dramatically, increased (by over 100%) to 7.0% (18/2/84 report). A cautionary note regarding the need for visual checks on a regular basis was again attached.

Up to, and including, the 7/5/85 tests, the LBS estimate along the critical rope section varied between 5.0% and 7.0%. Another sudden, and dramatic (again of over 100%) jump in the LBS estimate (to 12.0%) occurred on 5/10/85. Again, the recomendation for visual examinations at regular intervals was repeated. The 13/1/86 test restated a maximum LBS of 12.0% (actually this could have been 16.0% in our view) some 80-90 ft below the c/w, plus a note re. excessive crown-wire and interstrand wear, in addition to possible broken wires.

Conclusion: in the authors' view the foregoing sequence of EM reports, entirely on its own (i.e., disregarding any other information that was then to hand), clearly reflected the precarious situation that had developed in this rope by 13/1/86. In retrospect, it would have been desirable to remove the rope, even though the estimated LBS_{max} had not, in fact, reached the level mandated for tail-ropes by the New Brunswick regulations at that time. Additional information from previous similar instances was available, namely:

(1) a rope of identical size and construction (reel #010348) was used previously in the same location, from 19/6/79 to 11/6/82 (i.e., only for 36 months). It was tested with the Rotesco AC instrument at regular intervals. The 16/4/81 test showed no appreciable loss. An LBS of 5.0% was noted 95 ft below the c/w on 11/9/81 already. This value increased dramatically (by over 100%) to 11.0% as per the 13/3/82 test report, and even more dramatically to 26.0% as per the 19/5/82 test report, again in the critical rope-loop segment below the c/w. The rope was removed on 11/6/82.

(2) another rope of identical size and construction (reel #020581) was used previously as a companion rope (T.R.#2) from 19/6/79 to 11/6/82 (i.e., again only for 36

months). It too, showed a dramatic increase of estimated LBS between a test on 13/3/82 (18.0% at 100 ft below the c/w) and one on 19/5/82 (28.0% at 100-150 ft below the c/w, with 39 broken wires, plus flattened crown strands, as well as corrosion). It was removed on 11/6/82.

(3) the failure of a companion rope at the Kidd Creek mine, in Ontario, was known to have occurred on 7/4/82. This rope, too, was of $2\frac{1}{4}$ in. nominal diam., 6 × 7 construction (6 outer wires of .250-.251 in. diam, and 1 centre one of .265 in. diam). This rope was installed on 20/1/79, and failed after a service of $39\frac{1}{2}$ months, about 84 ft below the North skip. The static loop diameter on this friction hoist was 186 in., vs the 210 in. diam at B.M.&S. The rope length at Kidd Creek was 5200 ft, vs 3900 ft at B.M.&S. In other words, conditions were comparable.

Rotesco AC tests were performed on the sister rope at Kidd Creek (reel #010505) on 8.12.79; 12/4/80; 23/8/80; 13/12/80; 11/4/81; 15/8/81; and 12/12/81. The maximum LBS (LBS_{max}) was reported some 40 to 125 ft below the skip, and close to the c/w as well, i.e., in the same critical rope segments as at B.M.&S. However, the magnitude of the reported LBS_{max} appeared to be of little concern. It rose from 2.0% (on 13/12/80) to 4.5% (on 12/12/81). The destructive tests performed on 8.5 ft rope segments obtained from the sister rope after the catastrophic failure on 7/4/82, however, told a different story. Then, the "true" LBS in the critical rope loop segment below the skip was seen to be in the order of 36.0% to 40.0%, and some 18.0% below the c/w. These results were also available by June 1982, i.e., well before the catastrophic failure on 4/2/86 at the New Brunswick mine.

Case (b)

Brunswick Mining & Smelting Corp. Ltd., Bathurst, N.B.

2.29 in. nominal rope diam., 6 × 7 construction (6 outers @ .237-.238 in., and 1 centre @ .247 in.)

#3 Shaft; South Skip; T.R.#3; Reel #545270-3

Installed: 3/3/86; Strand failed: 28/8/87 (after $17\frac{1}{2}$ months of service) about 300 ft below the skip.

The operational history of an earlier companion rope (reel #010348) was discussed in the foregoing (case a.). This rope (case b.) was also examined with both the

Rotesco AC and the Rotescograph instruments (on 31/5/86; 16/11/86; and 7/4 as well as 13/5/87). Neither the LBS estimates (maximum reported on 13/5/87 was only 2.5%) nor the LF patterns gave rise to any concern that this rope might be nearing the end of its operational life.

Conclusion: the EM reports gave no indication of an impending rope failure. However, the problems with its companion ropes were well known.

Case (c)

Brunswick Mining & Smelting Corp. Ltd., Bathurst, N.B.

2.29 in. nominal rope diam., 6 × 7 construction (6 outers @ .237-.238 in., and 1 centre @ .247 in.)

#3 Shaft; North Skip; T.R.#2; Reel #M243530-3

Installed: 18/2/83; Failed: 3/2/85 (after $23\frac{1}{2}$ months of service) about 110 ft below the counterweight (c/w).

This rope was examined with the Rotesco AC instrument (on 4/3/83; 1/9/83; 3/3/84; 21/6/84; and 8/9/84). The Rotesco DC tester was also used on 9/9/84. Location of the greatest concentration of broken wires was correctly reported to be some 60-230 ft below the c/w, and that of the greatest LBS over the first 850 ft below the c/w. A cautionary note re. interstrand nicking and corrosion, and consequently the need for visual checks on a regular basis, was also appended to the latest report. However, quantitatively, none of the reports spoke of more than 4.0% LBS. This is inconsistent with the EM reports that were submitted on the previous rope in the same location.

Conclusion: the EM reports, *per se*, gave no indication of an impending rope failure. However, trouble could have been anticipated, in view of the operational history of the previous rope in the same location (reel #010342), and that of the latter's two companion ropes (reels #020583A and #020583B). The histories of the latter three ropes are discussed hereunder:

(1) $2\frac{1}{8}$ in. nominal rope diam., 6 × 7 construction (6 outers @ .237-.238 in., and 1 centre @ .247 in.)

#3 Shaft; North Skip; T.R.#2; Reel # 010342; Installed: 11/5/81; Removed: 16/2/83 (after 21 months of service).

This rope was examined with the Rotesco AC instrument (13/3/82; 19/5/82; 13/9/82; 5/1/82) and with the Rotesco DC tester (5/11/82). The Rotesco AC reports consistently pointed to a rope location some 85-110 ft below the c/w as the critical one. In addition they indicated a dramatic increase of the LBS_{max} from 3.0% (on 13/3/82) to 8.0% (on 19/5/82), to 10.0% (on 13/9/82), and finally to 12.0% (on 5/11/82). In addition, the 5/11/82 DC instrument report also noted well established corrosion in the area of concern. A Magnograph report of 11/11/82 confirmed the location of primary LBS, and the presence of severe corrosion in the area below the c/w. It estimated the LBS_{max} to be in the order of 20-22%, in view of the recent (7/4/82) failure of a similar rope at the Kidd Creek mines in Ontario. It should also be noted that the Magnograph operator was not aware of the previous NDT rope history. An important point is that no NDT testing should be done in isolation! Subsequent (on 17/6/83) destructive testing established a "true" LBS_{max} of some 7.0%.

(2) $2\frac{1}{8}$ in. nominal rope diam., 6 x 7 construction (6 outers @ .237-.238 in., and 1 centre @ .247 in.)

#3 Shaft; North Skip; T.R.#1; Reel # 020583A

Installed: 20/2/81; Removed: 18/2/83 (after 24 months of service).

This rope was examined with the Rotesco AC instrument (13/3/82; 17/5/82; 13/9/82; 5/11/82) and with the Rotesco DC instrument (5/11/82). A Magnograph test was also obtained on 11/11/82.

The Rotesco AC reports indicated a dramatic increase of the LBS_{max} from 3.0% (13/3/82) to 11.0% (17/5/82) at some 85-100 ft below the c/w. This value then rose to 12.0% (13/9/82), and to 13.0% (5/11/82), with the DC report noting, in addition, well established corrosion in the area of concern. The 11/11/82 Magnograph report confirmed the location of primary LBS, and the presence of corrosion. The LBS_{max} was again overestimated by the Magnograph operator (thought by him to be in the order of 24-26%), for the same reasons as mentioned above in case of T.R. #2. Subsequent (25/5/83) destructive tests established a "true" LBS_{max} of some 5.0%.

(3) $2\frac{1}{8}$ in. nominal rope diam., 6 x 7 construction (6 outers @ .237-.238 in., and 1 centre @ .247 in.)

#3 Shaft; North Skip; T.R.#3; Reel # 020583B

Installed: 14/4/81; Removed: 18/2/83 (after 22 months of service).

The final Rotesco AC and Rotesco DC reports (5/11/82) indicated an LBS_{max} of some 3.5%, and broken wires at the critical rope location (some 150-290 ft below the c/w). The corresponding Magnograph report of 11/11/82 confirmed the presence of broken wires (but found no advanced corrosion), plus an LBS_{max} of some 6.0%, at the same rope location.

Case (d)

Brunswick Mining & Smelting Corp. Ltd., Bathurst, N.B.

$1\frac{3}{4}$ in. nominal rope diam., 6 × 30 galvanized, F.S. construction (outers: 3 – .120 in.; inners: 3 – .036 in.; fillers: 12 – .074 in.; center: 12 – .124 in. diam wires)

#2 Shaft; West Skip (Comp. #2); Hoist Rope; Reel #447000-1

Installed: 24/5/85; Failed: 18/5/86 (after 12 months of service), near the cross-over point of the second and third rope layers on the hoist-drum, some 900 ft above the skip.

This rope was examined with both the Rotesco AC and Rotescograph instruments (17/9 and 19/9/85; 16/1/86). The first test reports referred to an LBS_{max} of 2.5%, and to broken wires in the rope section of eventual critical interest. In the 16/1/86 Rotesco reports the LBS_{max} was again listed as being 2.5%, while broken wires were indicated at 2069 ft above the skip. A reel-to-reel test was performed with the Rotescograph instrument on 21/5/86, subsequent to the rope's failure, along about 100 ft of the rope (i.e., the segment that is said to contain the second flange cross-over point). Apart from a slight irregularity at 13 ft, no indication of any serious rope deterioration was found in either the LF or the LMA channel.

Subsequent (5/6/86) tests at the Ontario MOL's Rope Testing Laboratory told a different story:

(1) MOL test #66247, of a 17'-4" rope section taken from immediately adjacent to the failure point, showed extensive wear, flattening and distortion of the outer wires, plus corrosion and pitting;

(2) MOL test #66246, of an 8'-0" rope section taken between 17'-4" and 25'-4" from the failure point, noted an LBS of some 10.0%, as well as crown-wire wear and flattening, besides four broken wires in a strand.

Conclusion: in view of the above it is difficult to understand why the NDT tests did not pick up the rope deterioration described by the MOL reports. In other words, it is hard to see how the situation arose that was described in the B.M.&S. plant superintendent's 27/5/86 report as follows: *the testing procedures, as conducted by Rotesco on this type of rope, would appear to be unable to predict this type of failure.* It is equally difficult to understand, however, why the lessons — i.e., the problems caused at the cross-over point by poorly fitted lifters on the hoist-drum — brought home already by the situation that had arisen in case of the previous hoist rope (same size, same construction) in the same location, were not heeded.

The previous ropes in Shaft #2 were reel #341930-1 (East Skip) and reel #341930-2 (West Skip). These were of identical size and construction to the subsequent set; they were installed on 17/9 and 18/9/84, and removed on 28/5/85 (a service life of 8 months). The East Skip rope was tested with both the Rotesco AC and Rotescograph instruments, on 2/5/85. A negligible LBS_{max} of 1.0%, and some broken wires (interestingly at 909 ft from the skip, i.e., at the location of eventual failure) were noted. A different picture emerged when a test sample, taken at 900 ft from the skip, was tested on 26/9/85 by the Rope Testing Laboratory of the Ontario MOL. It showed an LBS of some 33.0%, internal wear, nicking throughout, and many broken wires throughout the test length. The incongruous NDT vs DT results, and all the other results, were known well before the next rope failed on 18/5/86.

Case (e)

Denison Potacan Potash Co., Sussex, N.B.

$1\frac{7}{8}$ in. nominal rope diam., 34 × 7 galvanized, R.L.L. construction (34 @2.74 mm; 204 @ 2.64 mm)

#2 Shaft; T.R. #7; Reel: #G1074

Installed: 7/6/85; Removed: 15/12/88 (after 42 months of service).

The tail-rope, discussed previously as case (a), failed at an estimated LBS_{max} well below the level of LBS allowed for by the New Brunswick regulations. The tail-rope presently of interest did not, actually, fail. Even so, though, we think that leaving it in service until an LBS_{max} of 30.0% was reported by the Rotesco AC tester on 3/10/88 was inadvisable, especially after a previous LBS_{max} report, on 29/9/87, of 7.0% (we could not locate the relevant NDT report, presumably obtained halfway between the two foregoing dates). The regulations in effect at the time were adhered to. In the

light of this experience perhaps the maximum permissible LBS for tail-ropes in the New Brunswick regulations need to be reviewed, with a view towards redefinition.

Case (f)

Denison Potacan Potash Co., Sussex, N.B.

$1\frac{1}{4}$ in. nominal rope diam., 1×148 FLC, galvanized, Right Lay outer gallery construction (37 @ 2.74 mm; 64 @ 2.49 mm; 22 @ 2.25 mm; 12 @ 2.46 mm; 6 @ 1.14 mm; 6 @ 2.79 mm; 1 @ 3.12 mm diam wire).

Reel: #R28-P8391-FH194

Installed: 15/4/87; Removed: 20/10/88 (after 18 months of service).

This rope was non-destructively tested with the Rotesco AC instrument on 26/9/87; 5/3/88; and 29/9/88. Also, with the Magnograph on 19/10/88, and the NDT Technologies LMA-250 series instrument on 20/10/88.

The first two Rotesco AC tests reported LBS_{max} values at the two rope ends, close to the North and the South skips. In the case of the South skip rope end these two early values amounted to 1.5% and 4.0%, over the first 60 ft. In the case of the North skip rope end the respective values were 1.5% and 3.0%, over the first 55 ft. Then, on 29/9/88, the Rotesco AC tester noted a dramatic change: 10.0% LBS_{max}, due to a sharp deflection around 180 ft above the South skip, with no less than 9.0% LBS between 140 ft and 180 ft above the South skip. The LBS increase to 5.0% between 90 ft and 210 ft above the North skip was less dramatic. It is interesting to note, though, the additional information obtained with the other two instruments in October, 1988:

(a) with the LMA-250 series instrument: a considerable worsening of rope conditions (as compared to the rest of the rope) was observed over some 400 ft adjacent to the South skip, with an LMA_{max} of no less than 23.0% reported at 210 ft above this skip. At the other rope end, some 15 ft from the test-start above the North skip, the chart indicated an LMA of some 6.0%. While the operator refused to supply corresponding LBS estimates, it is clear that they would exceed his LMA data;

(b) with the Magnograph the considerably deteriorated rope section (as compared to the rest of the rope) extended along some 300 ft above the South skip, with an LMA_{max} of 10.5% (corresponding to an LBS_{max} of 13.0%) some 170 ft above

this skip. At the other rope end, about 210 ft from test-start above the North skip, the chart indicated an LMA of some 6.5%.

Conclusion: there is good agreement between the Rotesco AC, Magnograph, and NDT Technologies instruments as to: (1) the general location and length of the worst rope segment, and (2) the location of the rope section containing the LBS_{max}. However, the Rotesco AC report refers to an LBS_{max} of 10.0%, the Magnograph to an LBS_{max} of 13.0%, and the NDT Technologies tester to an LMA_{max} of no less than 23.0%. Should the latter be the correct value (a matter to be examined in a forthcoming report), the rope was dangerously close to failing.

Case (g)

Potash Company of America, Sussex, N.B.

Service Shaft, Hoist Rope H1

$1\frac{1}{8}$ in. nominal rope diam., 1 × 113 FLC, Right Lay outer gallery construction (36 @ .105 in.; 14 @ .110 in.; 14 @ .108 in.; 16 @ .104 in.; 8 @ .091 in.; 8 @ .068 in.; 8 @ .068 in.; 8 @ .102 in.; 8 @ .053 in.; 1 @ .091 in. diam wire).

Reel: #14211/2; Rope: #908001-01-2

Installed: 8/1/83; Removed: 4/10/83 (after 9 months of service).

This rope was non-destructively tested with the Rotesco AC instrument on 6/9/83. An LBS_{max} of 12-13% was reported, 200-300 ft above the cage, and an LBS of 9-10% between 80-160 ft above the skip. Subsequent visual and destructive testing was undertaken on a 10 ft long rope sample (exact origin along the rope of this sample is unknown to the authors). Its LBS, relative to the original rope breaking-strength, was 5.2%.

Conclusion: even without the destructive test result, it should have seemed unlikely that this FLC rope had, in fact, deteriorated to the extent indicated by the Rotesco AC report. Our previous (1, 2), and present, reports suggest that: (a) NDT testing of FLC ropes quite often err on the side of underestimating (often even to the extent of reporting LBS=0% values) rather than overestimating the "true" LBS values — which, in any case, are often misleading due to work-hardening effects, and (b) that FLC ropes, as a rule, last much longer than the 9 months attained this time. We, therefore, question why the very first Rotesco AC examination should have resulted in such a considerable

LBS of 12-13%. Also, this was an isolated result, which should, probably, have been carefully double, and even triple, checked before removing the rope.

Case (h)

Renabie Gold Mines Ltd., Missanabie, Ontario.

Hoist Rope

1.000 in. nominal rope diam., 18 × 7 IWRC 7 × 7 R.S., N.R. construction

Reel: #6-310

Installed: 29/3/86; Failed: 10/10/87 (after $18\frac{1}{2}$ months of service), about 126 ft above the skip-over-cage conveyance.

This rope was non-destructively tested with the Rotesco AC instrument on 14/9/86; 28/2/87; and 30/6/87. The LBS_{max}, and its location, was reported to be: 2.0% at 250-270 ft above the skip (14/9/86); 4.5% at 90-120 ft above the skip (28/2/87); and finally (30/6/87) 5.5% at 80 ft above the skip.

Subsequent to the rope's failure a series of destructive (DT) and non-destructive (NDT) tests were performed on a set of rope samples in November, 1987. The Rotescograph was used on this occasion for the NDT examinations. These tests resulted in the following data pairs:

at 33.5-41.5 ft from the conveyance: 4.0% (NDT) vs 10.8% (DT);

at 60.5-68.5 ft from the conveyance: 31.0% (NDT) vs 30.2% (DT);

at 77.5-85.5 ft from the conveyance: 34.0% (NDT) vs 30.1% (DT); and

at 85.5-93.5 ft from the conveyance: 32.0% (NDT) vs 34.7% (DT).

Conclusion: (a) this is an example of the problems inherent in EM testing the non-rotating type rope constructions, with their characteristically extremely localized type of defects; (b) the final LBS_{max} estimate of 5.5% (with the Rotesco AC tester) was, obviously, dangerously misleading; (c) the Rotescograph's LBS estimates, obtained, it will be noted, after the catastrophic rope-failure, are reasonably close to the comparative "true" LBS values; (d) this might suggest a substantial difference between the accuracy of the two Rotesco instruments. It may be noted, however, that the LBS estimates of

these two testers seemed always to agree, whenever they were used concurrently by the same operator elsewhere.

SUMMARY CONCLUSIONS

In this report, and in the two preceding ones (1, 2), project objectives were addressed through an in-depth analysis of an extensive range of LBS estimates, and of the corresponding destructive rope test results. It will be noted that, in these reports, the basic physical EM instrument characteristics, and their influence upon the test results and user preferences, were not detailed. These problems will be addressed in forthcoming reports, which will be based upon MRL's contracted work. In the present report results of the contracted work are touched upon only marginally (Table 9).

Our major contract objectives have been addressed, all the same, by the conclusions we have reached. For easy reference, our previous conclusions were listed in this report's *Introduction*. In this report they have been carefully re-examined, and re-confirmed, in the light of additional data.

In general terms we now conclude: (1) that, under present conditions, there is no justification for restricting "official" EM testing to the Rotesco AC instrument, (2) that LBS estimates, based upon measurements with EM instruments that produce charts recording both LMA and LF data, are demonstrably more accurate — within the meaning of Ontario's Performance Requirements — than the ones with only LMA records, (3) that even these LMA/LF based LBS estimates are inadequate — again within the meaning of Ontario's Performance Requirements — due, mostly, to the inadequacy of the whole process, rather than to any specific instrument shortcomings *per se*, (4) that it is advisable to re-examine several aspects of the regulations that govern these NDT tests at present, such as: (a) the nature of the end product demanded (e.g., loss-of-breaking-strength), (b) the level of operational accuracy demanded, (c) the question of who is qualified to operate the EM instruments, and which instruments can be used, and (d) the 30% LBS allowed for balance-ropes.

More specifically we recommend that after consultation with all interested parties, necessary steps be taken:

(1) to omit, at any rate in its present form, the instrument "approval" aspect from the mining regulations. It seems neither justified, nor even advantagous, that the regulatory authorities assume this added burden. We do agree that an independent guarantee should be available to both the authorities, and to prospective

instrument buyers, as to the tester's capabilities. The question, however, of who, and how, is to provide such an assurance, is an open one.

Years ago the situation was different. Then there was only a single Canadian designed and built instrument with a proven track record. Its primary output is a measure of the rope's L.M.A. Its mandatory use has, unquestionably, made mine-shaft hoisting severalfold safer. Other instruments, with both LMA and LF chart traces, have, however, been developed since. We document comparative performances in Tables 4 and 9.

(2) to omit, at any rate in its present form, the instrument operator's "competency" aspect from the mining regulations. It seems neither justified, nor even advantagous, that the regulatory authorities assume this added burden. We agree that the operators must possess a multitude of skills, and be well acquainted with a wide variety of operational parameters — both present and past —relating to the ropes being tested. The question of who is to attest operator "competency" is, however, an open one. As an example, our research shows that test results obtained with mine-owned and operated instruments are as acceptable as are those of service companies. In this context several points are worth noting:

(a) Quebec's proposal to let mine operators themselves be responsible for retiring their ropes, whenever these attain the mandated rope conditions, by allowing them to freely choose an appropriate service company with the required know-how and instrumentation. This arrangement allows for the usual free-market forces to assert themselves, such as availability, reliability, knowledgeability, cost effectiveness, satisfaction with services rendered, and the like;

(b) the European custom, notably in West Germany, Switzerland, Hungary and Poland, to let Centers of Excellence have the delegated authority, and thereby responsibility, to perform the "official" EM testing. These centers are mostly Universities and/or non-commercial Research Institutes. In some cases it involves the design of the instruments as well, besides performance of the field and laboratory measurements. In others it involves only the latter. In either case, however, a whole group of experts is ultimately responsible for declaring a rope fit for further service, and not just one individual. In fact the composition of the group may change over time. Such a group usually includes experts in the general areas of mining, mechanical and electrical engineering, hoisting, rope fabrication, EM instrument design and usage, and the like. The group is always well aware

of the entire mine operation in question, including shaft-conditions, rope operating and constructional details, etc., both past and present;

(c) that, as an extension of the foregoing point, these Centers of Excellence may also authorize individual mines to own and operate their own instruments;

(d) that it is essential to ensure, that individual NDT reports not be treated in isolation. They must be obtained, and subsequently evaluated, in full knowledge of the entire operational history of the rope being tested, as well as of its predecessors and, if feasible, even of its companion ropes at other locations (e.g., note cases discussed in the "Rope Failures" section of this report). The advantages of group decisions (see point b. above) follow logically.

Moreover, we recommend:

(3) that, under all circumstances, some members of the mine staff, apart from the authorities and the instrument operators, be well acquainted with the intricacies of EM chart evaluation techniques. Ultimately, they should be responsible for questioning, and possibly rejecting, dubious reports. It is, therefore, essential that those authorities — who include among their rope removal criteria LBS data that are based upon EM instrument tests — insist that EM test reports contain an itemized, and clearly identified listing of: (a) the Local Faults detected (type and location), (b) the LMA observed (magnitude and location), and (c) the estimated LBS.

Moreover, we suggest that the authorities also insist that the exact location along the operational rope of the samples sent for statutory destructive testing be clearly identified. Occasionally these rope locations will be covered by the statutory EM tests as well. In these cases valuable comparative NDT/DT data-pairs will be available, at no extra cost;

(4) that, in all cases the authorities insist that (apart from the usual information) EM test reports and charts always include: (a) all information relating to instrument and recorder calibration settings, (b) the rope's reel number, (c) information about the exact location where the test was started — possibly by noting the exact location (say respective to the skip or conveyance) of an easily identifiable marker, temporarily affixed to the rope, and (d) in case of ropes that had to be tested at both ends seperately, the placement of an easily identifiable temporary marker on the rope, so that the chart-lengths can be easily and reliably spliced

together at this point. Lack of the foregoing data has caused us many a problem, and occasional uncertainty, during our research.

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APPENDIX

Tables 1, 2, 3, 5, 6, 7, and 9

as well as Figures 1, 1a, 1b, 1c, 2, 3, and 3a

TABLE 1

Locked Coil Ropes — Comparative NDT/DT Results

No.	Mine*	Rope			Service			Destr. test (DT)			Non-destr. test (NDT)			Error	OML Sp.
		Size	Constr.	Reel (rope) #	On:	Off:	Months	Date	No.**	%	Date	Instr.***	%	%	Test No.
1	A	$\frac{15}{16}$	1 × 88	79070	5.7.79	29.4.87	$93\frac{1}{2}$	9.12.87	67627	-15.6	10.2.87	a	-9.6	-6.0	#533
											13.3.87	b	-11.8	-3.8	
								11.12.87	67628	-11.2	10.2.87	a	-6.4	-4.8	
											13.3.87	b	-7.5	-3.7	
								11.12.87	67629	-23.5	10.2.87	a	-8.8	-14.7	
											6.4.87	c	-17.5	-6.0	
								11.12.87	67630	-10.5	10.2.87	a	-7.1	-3.4	
											6.4.87	c	-11.0	+0.5	
								11.12.87	67631	-7.7	10.2.87	a	-2.8	-4.9	
											13.3.87	b	-3.1	-4.6	
											6.4.87	c	-2.0	-5.7	
								7.12.87	67632	-11.4	10.2.87	a	-5.3	-6.1	
											13.3.87	b	-7.6	-3.8	
											6.4.87	c	-8.0	-3.4	
								7.12.87	67624	-0.4	6.4.87	c	0.0	-0.4	
								7.12.87	67625	-0.4	10.2.87	a	0.0	-0.4	
											13.3.87	b	0.0	-0.4	
								4.12.87	67626	+1.0	10.2.87	a	0.0	+1.0	
											13.3.87	b	0.0	+1.0	
2	A	$\frac{15}{16}$	1 × 88	79071	5.7.79	29.4.87	$93\frac{1}{2}$	7.12.87	67636	-8.3	10.2.87	a	-5.0	-3.3	
											13.3.87	b	-10.0	+1.7	
											6.4.87	c	-8.0	-0.3	
								8.12.87	67638	-3.4	6.4.87	c	-2.5	-0.9	

TABLE 1 (continued)

Locked Coil Ropes — Comparative NDT/DT Results

No.	Mine*	Rope			Service			Destr. test (DT)			Non-destr. test (NDT)			Error	OML Sp.
		Size	Constr.	Reel (rope) #	On:	Off:	Months	Date	No.**	%	Date	Instr.***	%	%	Test No.
2	A	$\frac{15}{16}$	1 × 88	79071	5.7.79	29.4.87	$93\frac{1}{2}$	11.12.87	67640	−8.1	10.2.87	a	−2.1	−6.0	#533
											13.3.87	b	−4.9	−3.2	
											6.4.87	c	−7.0	−1.1	
								11.12.87	67641	−7.8	13.3.87	b	−2.8	−5.0	
											6.4.87	c	−2.5	−5.3	
								4.12.87	67633	+2.2	6.4.87	c	0.0	+2.2	
								4.12.87	67634	+1.9	10.2.87	a	0.0	+1.9	
											13.3.87	b	0.0	+1.9	
								4.12.87	67635	+1.8	10.2.87	a	0.0	+1.8	
											13.3.87	b	0.0	+1.8	
								11.12.87	67639	−6.1	10.2.87	a	−2.5	−3.6	
											13.3.87	b	−1.8	−4.3	
											6.4.87	c	−2.0	−4.1	
								7.12.87	67637	+1.0	10.2.87	a	−2.1	+3.1	
											13.3.87	b	−2.1	+3.1	
3	A	$\frac{15}{16}$	1 × 88	79072	5.7.79	29.4.87	$93\frac{1}{2}$	8.12.87	67645	−13.7	10.2.87	a	−5.0	−8.7	
											13.3.87	b	−12.5	−1.2	
								9.12.87	67646	−6.5	6.4.87	c	−5.0	−1.5	
								7.12.87	67648	−5.4	10.2.87	a	−2.5	−2.9	
											6.4.87	c	−3.0	−2.4	
								8.12.87	67647	−4.7	10.2.87	a	−2.5	−2.2	
											13.3.87	b	−5.0	+0.3	

TABLE 1 (continued)

Locked Coil Ropes — Comparative NDT/DT Results

No.	Mine*	Rope			Service			Destr. test (DT)			Non-destr. test (NDT)			Error	OML Sp.
		Size	Constr.	Reel (rope) #	On:	Off:	Months	Date	No.**	%	Date	Instr.***	%	%	Test #
3	A	$\frac{15}{16}$	1 × 88	79072	5.7.79	29.4.87	$93\frac{1}{2}$	9.12.87	67649	-8.7	10.2.87	a	-5.0	-3.7	#533
											13.3.87	b	-9.6	+0.9	
											6.4.87	c	-10.0	+1.3	
								4.12.87	67642	+2.6	6.4.87	c	0.0	+2.6	
											10.2.87	a	0.0	+2.6	
								4.12.87	67643	+1.8	10.2.87	a	0.0	+1.8	
											13.3.87	b	0.0	+1.8	
								4.12.87	67644	+3.1	10.2.87	a	0.0	+3.1	
											13.3.87	b	0.0	+3.1	
4	A	$\frac{15}{16}$	1 × 88	79073	5.7.79	29.4.87	$93\frac{1}{2}$	8.12.87	67657	-5.0	10.2.87	a	-2.5	-2.5	
											13.3.87	b	-5.8	+0.8	
											6.4.87	c	-5.0	0.0	
								10.12.87	67658	-7.2	10.2.87	a	-4.2	-3.0	
											13.3.87	b	-5.2	-2.0	
											6.4.87	c	-4.0	-3.2	
								11.12.87	67659	+2.0	10.2.87	a	-1.8	+3.8	
											13.3.87	b	-1.6	+3.6	
								10.12.87	67661	+0.4	10.2.87	a	-1.8	+2.2	
											13.3.87	b	-1.6	+2.0	
								8.12.87	67660	-0.3	10.2.87	a	-1.8	-1.5	
											13.3.87	b	-1.6	-1.3	
								4.12.87	67652	+1.4	6.4.87	c	0.0	+1.4	
								10.12.87	67650	-3.5	10.2.87	a	0.0	-3.5	
											13.3.87	c	0.0	-3.5	

TABLE 1 (continued)

Locked Coil Ropes — Comparative NDT/DT Results

No.	Mine*	Rope			Service			Destr. test (DT)			Non-destr. test (NDT)			Error	OML Sp.
		Size	Constr.	Reel (rope) #	On:	Off:	Months	Date	No.**	%	Date	Instr.***	%	%	Test No.
4	A	$\frac{15}{16}$	1 × 88	79073	5.7.79	29.4.87	$93\frac{1}{2}$	10.12.87	67651	−0.8	10.2.87	a	0.0	−0.8	#533
											13.3.87	c	0.0	−0.8	
								11.12.87	67653	−10.7	10.2.87	a	−5.7	−5.0	
											13.3.87	b	−7.2	−3.5	
											6.4.87	c	−8.5	−2.2	
								10.12.87	67654	−1.0	10.2.87	a	−2.8	+1.8	
											13.3.87	b	−3.2	+2.2	
								11.12.87	67656	−5.3	6.4.87	c	−1.0	−4.3	
								11.12.87	67655	−2.8	10.2.87	a	−2.1	−0.7	
											13.3.87	b	−2.6	−0.2	
5	A	1.000	1 × 105	031811 (TCH-82099)	8.1.83	23.5.87	$94\frac{1}{2}$	24.3.88	67980	+3.9	10.5.87	a	−1.0	+4.9	
											10.5.87	b	−1.0	+4.9	
											3.5.87	c	0.0	+3.9	
											10.5.87	e	0.0	+3.9	
								24.3.88	67981	+4.1	10.5.87	a	−1.0	+5.1	
											10.5.87	b	−1.0	+5.1	
											3.5.87	c	0.0	+4.1	
											10.5.87	e	0.0	+4.1	
								24.3.88	67982	+4.0	10.5.87	a	−1.0	+5.0	
											10.5.87	b	−1.0	+5.0	
											3.5.87	c	0.0	+4.0	
											10.5.87	e	0.0	+4.0	

TABLE 1 (continued)

Locked Coil Ropes — Comparative NDT/DT Results

No.	Mine*	Rope			Service			Destr. test (DT)			Non-destr. test (NDT)			Error	OML Sp.
		Size	Constr.	Reel (rope) #	On:	Off:	Months	Date	No.**	%	Date	Instr.***	%	%	Test No.
5	A	1.000	1 × 105	031811 (TCH-82099)	8.1.83	23.5.87	94½	24.3.88	67983	+0.5	10.5.87	a	-6.0	+6.5	
											10.5.87	b	-7.4	+7.9	
											3.5.87	c	-2.3	+2.8	
											10.5.87	e	-6.0	+6.5	
								24.3.88	67984	-13.1	10.5.87	a	-5.7	-7.4	
											10.5.87	b	-12.9	-0.2	
											3.5.87	c	-12.1	-1.0	
											10.5.87	e	-12.0	-1.1	
								24.3.88	67985	+3.2	10.5.87	a	0.0	+3.2	
											10.5.87	b	0.0	+3.2	
											3.5.87	c	-1.0	+4.2	
											10.5.87	e	—	—	
6	A	1.000	1 × 105	031809 (TCH-82100)	8.1.83	23.5.87	94½	23.3.88	67986	+4.8	10.5.87	a	-1.0	+5.8	
											10.5.87	b	0.0	+4.8	
											3.5.87	c	0.0	+4.8	
											10.5.87	e	0.0	+4.8	
								23.3.88	67987	+3.4	10.5.87	a	-1.0	+4.4	
											10.5.87	b	0.0	+3.4	
											3.5.87	c	0.0	+3.4	
											10.5.87	e	0.0	+3.4	
								23.3.88	67988	+5.0	10.5.87	a	-1.0	+6.0	
											10.5.87	b	0.0	+5.0	
											3.5.87	c	0.0	+5.0	
											10.5.87	e	0.0	+5.0	

TABLE 1 (continued)

Locked Coil Ropes — Comparative NDT/DT Results

No.	Mine*	Rope			Service			Destr. test (DT)			Non-destr. test (NDT)			Error	OML Sp.
		Size	Constr.	Reel (rope) #	On:	Off:	Months	Date	No.**	%	Date	Instr.***	%	%	Test No.
6	A	1.000	1 × 105	031809 (TCH-82100)	8.1.83	23.5.87	94½	23.3.88	67989	0.0	10.5.87	a	−8.1	+8.1	
											10.5.87	b	−5.7	+5.7	
											3.5.87	c	−6.0	+6.0	
											10.5.87	e	−9.0	+9.0	
								23.3.88	67990	−9.9	10.5.87	a	−6.7	−3.2	
											10.5.87	b	−12.9	+3.0	
											3.5.87	c	−17.2	+7.3	
											10.5.87	e	−17.0	+7.1	
								23.3.88	67991	+3.4	10.5.87	a	−3.2	+6.6	
											10.5.87	b	0.0	+3.4	
											3.5.87	c	−1.0	+4.4	
											10.5.87	e	—	—	
7	A	1.000	1 × 105	031808 (TCH-82101)	8.1.83	23.5.87	94½	15.4.88	67992	+3.3	10.5.87	a	0.0	+3.3	
											10.5.87	b	0.0	+3.3	
											3.5.87	c	0.0	+3.3	
											10.5.87	e	0.0	+3.3	
								15.4.88	67993	+3.4	10.5.87	a	0.0	+3.4	
											10.5.87	b	0.0	+3.4	
											3.5.87	c	0.0	+3.4	
											10.5.87	e	0.0	+3.4	
								15.4.88	67994	+3.1	10.5.87	a	0.0	+3.1	
											10.5.87	b	0.0	+3.1	
											3.5.87	c	0.0	+3.1	
											10.5.87	e	0.0	+3.1	

TABLE 1 (continued)

Locked Coil Ropes — Comparative NDT/DT Results

No.	Mine*	Rope			Service			Destr. test (DT)			Non-destr. test (NDT)			Error	OML Sp.
		Size	Constr.	Reel (rope) #	On:	Off:	Months	Date	No.**	%	Date	Instr.***	%	%	Test No.
7	A	1.000	1 × 105	031808 (TCH-82101)	8.1.83	23.5.87	94½	15.4.88	67995	-0.6	10.5.87	a	-5.0	-4.4	
											10.5.87	b	-9.0	-8.4	
											3.5.87	c	-4.5	-3.9	
											10.5.87	e	-7.0	-6.4	
								15.4.88	67996	-10.9	10.5.87	a	-6.7	-4.2	
											10.5.87	b	-13.5	+2.6	
											3.5.87	c	-11.0	+0.1	
											10.5.87	e	-13.0	+2.1	
								15.4.88	67997	+2.1	10.5.87	a	-1.4	+3.5	
											10.5.87	b	-1.5	+3.6	
											3.5.87	c	-1.0	+3.1	
											10.5.87	e	—	—	
8	A	1.000	1 × 105	031810 (TCH-82102)	8.1.83	23.5.87	94½	14.4.88	67998	+4.9	10.5.87	a	0.0	+4.9	
											10.5.87	b	0.0	+4.9	
											3.5.87	c	0.0	+4.9	
											3.5.87	e	0.0	+4.9	
								14.4.88	67999	+4.8	10.5.87	a	0.0	+4.8	
											10.5.87	b	0.0	+4.8	
											3.5.87	c	0.0	+4.8	
											3.5.87	e	0.0	+4.8	
								14.4.88	68000	+4.2	10.5.87	a	0.0	+4.2	
											10.5.87	b	0.0	+4.2	
											3.5.87	c	0.0	+4.2	
											3.5.87	e	0.0	+4.2	

TABLE 1 (continued)

Locked Coil Ropes — Comparative NDT/DT Results

No.	Mine*	Rope			Service			Destr. test (DT)			Non-destr. test (NDT)			Error	OML Sp.
		Size	Constr.	Reel (rope) #	On:	Off:	Months	Date	No.**	%	Date	Instr.***	%	%	Test No.
8	A	1.000	1 × 105	031810 (TCH-82102)	8.1.83	23.5.87	94½	14.4.88	68001	−1.5	10.5.87	a	−5.7	+4.2	
											10.5.87	b	−7.9	+6.4	
											3.5.87	c	−7.5	+6.0	
											3.5.87	e	−10.0	+8.5	
								14.4.88	68002	−8.8	10.5.87	a	−6.4	−2.4	
											10.5.87	b	−16.8	+8.0	
											3.5.87	c	−17.5	+8.7	
											3.5.87	e	−20.0	+11.2	
								14.4.88	68003	+3.7	10.5.87	a	−1.4	+5.1	
											10.5.87	b	0.0	+3.7	
											3.5.87	c	0.0	+3.7	
											3.5.87	e	—	—	
								14.4.88	68004	+1.2	10.5.87	a	−4.6	+5.8	
											10.5.87	b	−3.5	+4.7	
											3.5.87	c	−5.0	+6.2	
											3.5.87	e	—	—	
9	E	1⅛	1 × 113	14211-2	8.1.83	4.10.83	9	29.2.84	WRI	−6.0	6.9.83	a	−13.0	+7.0	
10	A	1.27	1 × 138	342621-2				15.12.86	66701	−11.2	12.4.86	b	−13.4	+2.2	
				342621-2				15.12.86	66700	+0.4	12.4.86	b	0.0	+0.4	
				342620-1				15.12.86	66697	−2.9	12.4.86	b	0.0	−2.9	
				342620-1				15.12.86	66696	−5.4	12.4.86	b	−7.3	+1.9	
				342620-2				15.12.86	66699	−6.2	12.4.86	b	0.0	−6.2	
				342620-2				15.12.86	66698	−9.0	12.4.86	b	−6.7	−2.3	

TABLE 1 (continued)

Locked Coil Ropes — Comparative NDT/DT Results

No.	Mine*	Rope			Service			Destr. test (DT)			Non-destr. test (NDT)			Error	OML Sp.
		Size	Constr.	Reel (rope) #	On:	Off:	Months	Date	No.**	%	Date	Instr.***	%	%	Test No.
11	D	1.31 ($1\frac{5}{16}$)	1 × 144	010257	1.10.79	28.4.86	79	26.8.86	66390	-1.8	15.4.86	a	-4.5	+2.7	#524
											8.8.86	c	-4.0	+2.2	
				010254	1.10.79	28.4.86	79	20.10.86	59090	+5.2	15.4.86	a	-4.0	+9.2	#525
											18.9.86	c	-3.9	+9.1	
				010256	1.10.79	28.4.86	79	20.10.86	66550	-0.4	15.4.86	a	-4.5	+4.1	#526
											18.9.86	c	-3.9	+3.5	
12	C	1.515	1 × 182	447730-1 (909485-119)	Sept.85	5.8.87	$23\frac{1}{2}$	19.1.88	67754	-11.1	2.7.87	a	-15.0	+3.9	#534
											21.7.87	b	-12.5	+1.4	
				04401-3 (907770-118)	24.7.85	4.8.87	$24\frac{1}{2}$	20.1.88	67389	-11.8	2.7.87	a	-12.1	+0.3	
											21.7.87	b	-10.0	-1.8	
13	D	$1\frac{1}{8}$	1 × 173	010227	19.6.79	28.6.86	84	27.2.87	66934	-7.2	14.1.86	a	-3.0	-4.2	#529
											16.4.86	c	-6.0	-1.2	
				010229	19.6.79	16.5.86	83	12.3.87	66946	-3.9	14.1.86	a	-6.5	+2.6	#530
											16.4.86	c	-7.0	+3.1	
14	B	$1\frac{3}{4}$	1 × 37▽	L-08242	23.2.72	21.11.87	189	22.6.88	68180	-4.8	7.11.87	a	-21.0	+16.2	#537
											17.11.87	b	-12.0	+7.2	
									68178	+4.4	21.6.88	a	-3.5	+7.9	
									68179	-4.8		a	-12.0	+7.2	
									68180	-4.8		a	-15.0	+10.2	

* : Mine: A = INCO (Thompson, Man.); B = Falconbridge (Ont.); C = CCP (Colonsay, Sask.); D = Brunswick Mining & Smelting (Bathurst, NB); E = PCA (Sussex, NB).

** : Destr. test No.: five digit no. is that of Rope Testing Laboratory, Ontario Ministry of Labour (OML); otherwise the identity of the laboratory performing DT is indicated.

*** : Instrument: a = Rotesco AC; b = Magnograph; c = Rotescograph; d = Rotesco DC; e = NDT Technologies, LMA Series 250.

▽ : half-lock guide rope (as is Item 46LC in CANMET Report #88-78)

TABLE 2

Non Rotating Ropes — Comparative NDT/DT Results

No.	Mine*	Rope			Service			Destr. test (DT)			Non-destr. test (NDT)			Error	OML Sp.
		Size	Constr.	Reel (rope) #	On:	Off:	Months	Date	No.**	%	Date	Instr.***	%	%	Test #
1	F	1.000	18 × 7	4-1027-B	28.3.86	14.10.87†	19	5.5.88	68134	-8.4	30.6.87‡	a	-6.0	-2.4	#536
											2.5.88**	a	-12.0	+3.6	
		1.000	18 × 7	6-310	29.3.86	10.10.87*	19	17.11.87	67556	-35.5	30.6.87‡	a	-5.5	-30.0	#532
											16.11.87††	c	-42.0	+6.5	
2	H1	$1\frac{1}{16}$	34 × 7*	R1 P7061 34B50	—	—	—	—	—	-18.8	19.12.83	b	-18.3	-0.5	
				R2 P7061 34B51	—	—		—	—	-12.0	19.12.83	b	-11.5	-0.5	
3	A	$1\frac{1}{2}$	—	Tail Rope #1	—	—	—	—	—	-37.3	15.2.86	a	-10.1	-27.2	
				T1 cage							15.2.86	b	-20.3	-17.0	
		$1\frac{1}{2}$	—	Tail Rope #2	—	—	—	—	—	-17.8	15.2.86	a	-7.3	-10.5	
				T1 cage							15.2.86	b	-15.4	-2.4	
4	H1	$1\frac{3}{4}$	34 × 7*	R4 P7061 34B53	—	—	—	—	—	-16.8	19.12.83	b	-16.0	-0.8	
5	G	$1\frac{3}{4}$	34 × 7	2441110-1 (21-10)	—	—	—	26.2.88	67449	-1.3	11.6.87	a	-11.9	+10.6	#535∩
											23.7.87	b	-16.9	+15.6	
		$1\frac{3}{4}$	34 × 7	2441110-1 (21-10)	—	—	—	26.2.88	67450	+8.2	11.6.87	a	-11.9	+20.1	
											23.7.87	b	-16.9	+25.1	
		$1\frac{3}{4}$	34 × 7	2441110-1 (20-08)	—	—	—	26.2.88	67451	+0.4	11.6.87	a	-14.0	+14.4	
											23.7.87	b	-18.5	+18.9	
6	E	$1\frac{7}{8}$	34 × 7	14213-3	14.6.85	15.1.88	$30\frac{1}{2}$	26.2.88	67806	-14.0	11.4.87	a	-16.0	+2.0	
7	H2	$2\frac{3}{32}$	34 × 17	R9 P6497 34B27	Feb., 81	15.5.87	75	18.6.87	WRI♣	-14.4	5.12.86	a	-7.0	-7.4	
				(T.R. #26)							14.5.87	b	-15.0	+0.6	

TABLE 2 — footnotes

* : Mine: A = International Nickel Co. — INCO (Thompson, Man.); E = Potash Co. of America — PCA (Sussex, NB); F = Renabie Gold Mines (Ont.); G = Intl. Mineral & Chemical Corp. — IMC (Esterhazy, Sask.); H1 = Potash Corp. of Saskatchewan — PCS (Lanigan, Sask.); H2 = PCS (Allan, Sask.)

** : Destr. test No.: five digit no. is that of Rope Testing Laboratory, Ontario Ministry of Labour (OML); otherwise the identity of the laboratory performing DT is indicated.

*** : Instrument: a = Rotesco AC; b = Magnograph; c = Rotescograph; d = Rotesco DC.

† : this is a companion rope of the rope (reel #6-310) that failed on 10.10.87;

o : rope failed;

‡ : in situ test;

†† : laboratory test;

•• : reel-to-reel test.

• : #2 shaft; Balance Rope #8.

∩ : localised faults; probably wrong samples destructively tested; omit from summary data analysis

♣ : Wire Rope Industries Ltd., Pointe Claire, Que.

TABLE 3

Stranded Ropes — Comparative NDT/DT Results

No.	Mine*	Rope			Service			Destr. test (DT)			Non-destr. test (NDT)			Error	OML Sp.
		Size	Constr.	Reel (rope) #	On:	Off:	Months	Date	No.**	%	Date	Instr.***	%	%	Test #
1	I	$\frac{3}{4}$	6 × 8	841330-1	16.4.8	in use	—	13.9.88	in-house	-10.0	18.8.88	c	-8.0	-2.0	
			6 × 7	41	11.3.86	12.1.88	25	29.4.87	in-house	0.0	8.4.87	c	-4.0	+4.0	
			6 × 7	41	11.3.86	12.1.88	25	2.9.87	in-house	-3.0	28.8.87	c	-5.0	+2.0	
			6 × 8	443170-1	8.10.85	17.7.86	11	20.6.86	in-house	-10.0	5.6.86	c	-15.0	+5.0	
			6 × 8	443170-1	8.10.85	17.7.86	11	15.7.86	in-house	-17.0	5.6.86	c	-20.0	+3.0	
2	I	1.000	6 × 19	1302-A	8.11.81	24.11.84	$36\frac{1}{2}$	10.1.84	in-house	-5.0	18.1.84	c	-7.0	+2.0	
			6 × 8	70462	25.11.83	in use	—	25.3.86	in-house	0.0	14.3.86	c	-8.0	+8.0	
3	J	1.000	6 × 26	—	July, 84	March, 85	8	30.10.85	65707	-68.3	22.10.85	c	-45.0	-23.3	#516
									65708	-54.1	22.10.85	c	-37.0	-17.1	
									65707	-68.3	1.3.85	a	-36.3	-32.0	
								30.10.85	65707	-68.3	1.3.85	d	-36.3	-32.0	
4	I	$1\frac{1}{4}$	6 × 8	441690-1	25.3.87	5.2.88	11	2.2.88	in-house	-12.0	19.1.88	c	-16.0	+4.0	
				—	9.5.84	8.2.85	9	21.9.84	in-house	0.0	12.9.84	c	-9.6	+9.6	
				440520-1	21.11.84	22.10.85	11	9.10.85	in-house	-8.0	8.10.85	c	-16.0	+8.0	
								18.10.85	in-house	-48.0	8.10.85	c	-16.0	-32.0	
				644360-2	14.9.87	in use	—	19.4.88	in-house	-9.0	18.5.88	c	-8.0	-1.0	
								24.5.88	in-house	-8.0	18.5.88	c	-9.0	+1.0	
				642630-7	4.9.86	14.9.87	$12\frac{1}{2}$	26.8.87	in-house	-7.0	15.7.87	c	-8.0	+1.0	
				96630	23.4.83	9.5.84	$12\frac{1}{2}$	8.5.84	in-house	-9.0	4.5.84	c	-12.0	+3.0	
				340250-2	9.9.83	4.1.85	16	7.11.84	in-house	-12.0	1.11.84	c	-18.0	+6.0	
								3.12.84	in-house	-14.0	1.11.84	c	-18.0	+4.0	
				448930-1	12.11.85	27.8.86	$11\frac{1}{2}$	28.8.86	in-house	-31.0	18.8.86	c	-30.0	-1.0	
				644260-1	14.3.87	27.5.88	14	17.5.88	in-house	-6.0	16.5.88	c	-4.0	-2.0	
				741480	5.2.88	15.11.88	$9\frac{1}{2}$	13.10.88	in-house	-14.0	28.10.88	c	-16.0	+2.0	

TABLE 3 (continued)

Stranded Ropes — Comparative NDT/DT Results

No.	Mine*	Rope			Service			Destr. test (DT)			Non-destr. test (NDT)			Error	OML Sp.
		Size	Constr.	Reel (rope) #	On:	Off:	Months	Date	No.**	%	Date	Instr.***	%	%	Test #
5	D	$1\frac{3}{4}$	6 × 27	447000-1	24.5.85	21.5.86°	12	5.6.86	66246	-10.2	16.1.86	a	-2.5	-7.7	
											16.1.86	c	-2.5	-7.7	
6	K	$1\frac{3}{4}$	6 × 30	741330-1 (57)	14.2.88	1.11.88	$8\frac{1}{2}$	10.1.89	68757	-13.2	1.11.88	a	-17.0	+3.8	
7	I	2.000	6 × 19	24035-2	22.12.82	4.12.83	$11\frac{1}{2}$	10.1.84	in-house	-23.0	3.12.83	c	-20.0	-3.0	
8	D	$2\frac{1}{8}$	6 × 7	010343	11.6.82	4.2.86°	46	3.3.86	65973	-11.0	13.1.86	a	-12.0	-1.0	
					8.10.85										
		$2\frac{1}{8}$	6 × 7	010342	11.5.81	18.2.83	21	17.6.83	63444	-6.6	17.1.86	c	-12.0	-1.0	
											5.11.82	a	-12.0	+5.4	#502
											11.11.82	b	-30.0	+23.4	
		$2\frac{1}{8}$	6 × 7	020583A	20.2.81	18.2.83	24	25.5.83	63347	-4.4	9.6.83	b	-3.7	-2.9	
											5.11.82	a	-13.0	+8.6	#503
											11.11.82	b	-26.0	+21.6	
											9.5.83	b	-26.8	+22.4	

* : Mine: D = Brunswick Mining & Smelting (Bathurst, N.B.); I = DEVCO (Sydney, N.S.); J = Ronald Bush Coal Co. (Penna, USA); K = Rio Algom (Ont.).

** : Destr. test No.: five digit no. is that of Rope Testing Laboratory, Ontario Ministry of Labour (OML); otherwise the identity of the laboratory performing DT is indicated.

*** : Instrument: a = Rotesco AC b = Magnograph c = Rotescograph d = Rotesco DC

o : rope failed.

Table 5

Analysis of test data obtained with Locked Coil (LC) ropes

(α) Total # of samples: ⟶	132							
(β) Instrument used: ⟶	NDT Tech. LMA 250		Rotesco AC		Rotescograph		Magnograph	
(γ) Using given tester: ⟶	# out of (α)	% of (α)	# out of (α)	% of (α)	# out of (α)	% of (α)	# out of (α)	% of (α)
	25	19	120	91	58	44	69	52
Of total (γ):	# out of (γ)	% of (γ)	# out of (γ)	% of (γ)	# out of (γ)	% of (γ)	# out of (γ)	% of (γ)
in the <10% DT range* (δ) ⟶	23	92	90	75	51	88	40	58
in the ≥10% DT range (ϵ) ⟶	2	8	30	25	7	12	29	42
Of total (δ): in the ≤ ±4% error range* ⟶	11	48	51	68	32	62	24	60
Of total (ϵ): in the ≤ ±4% error range* ⟶	2	100	5	17	6	83	25	83
Of total (γ): data with + error (ζ) (i.e., overestimates of LBS) ⟶	23	92	65	54	33	57	43	62
of (ζ), in the <10% DT range ⟶	22	96	60	93	32	97	31	81
Of total (γ): data with − error (η) (i.e., underestimates of LBS) ⟶	2	8	55	46	25	43	26	38
of (η), in the <10% DT range* ⟶	1	50	30	54	17	68	15	58

*: includes "work hardened" specimens, with a negative "true" LBS (many also with NDT=0%)

Table 6

Analysis of test data obtained with Non Rotating (NR) ropes

(α) Total # of samples: ⟶	36					
(β) Instrument used: ⟶	Rotesco AC		Rotescograph		Magnograph	
(γ) Using given tester: ⟶	# out of (α)	% of (α)	# out of (α)	% of (α)	# out of (α)	% of (α)
	34	94	1	3	9	25
Of total (γ):	# out of (γ)	% of (γ)	# out of (γ)	% of (γ)	# out of (γ)	% of (γ)
in the <10% DT range* (δ) ⟶	13	38	—	—	3	33
in the ≥10% DT range (ϵ) ⟶	21	62	1	100	6	67
Of total (δ): in the ≤ ±4% error range* ⟶	10	77	—	—	0	0
Of total (ϵ): in the ≤ ±4% error range ⟶	2	10	0	0	5	83
Of total (γ): data with + error (ζ) (i.e., overestimates of LBS) ⟶	12	35	1	100	4	44
of (ζ), in the <10% DT range* ⟶	10	83	0	0	3	75
Of total (γ): data with − error (η) (i.e., underestimates of LBS) ⟶	22	65	—	—	5	56
of (η), in the <10% DT range ⟶	2	9	—	—	0	0

*: includes "work hardened" specimens, with a negative "true" LBS (many also with NDT=0%)

Table 7

Analysis of test data obtained with Stranded (STR) ropes

(α) Total # of samples: ⟶	172					
(β) Instrument used: ⟶	Rotesco AC		Rotescograph		Magnograph	
(γ) Using given tester: ⟶	# out of (α)	% of (α)	# out of (α)	% of (α)	# out of (α)	% of (α)
	144	84	34	20	26	15
Of total (γ):	# out of (γ)	% of (γ)	# out of (γ)	% of (γ)	# out of (γ)	% of (γ)
in the <10% DT range* (δ) ⟶	55	38	16	47	9	35
in the ≥10% DT range (ϵ) ⟶	89	62	18	53	17	65
Of total (δ): in the ≤ ±4% error range* ⟶	37	67	11	69	5	56
Of total (ϵ): in the ≤ ±4% error range ⟶	25	28	7	39	8	47
Of total (γ): data with + error (ζ) (i.e., overestimates of LBS) ⟶	35	24	18	53	12	46
of (ζ), in the <10% DT range* ⟶	32	91	12	67	3	21
Of total (γ): data with − error (η) (i.e., underestimates of LBS) ⟶	109	76	16	47	14	54
of (η), in the <10% DT range ⟶	23	21	2	15	5	35

*: includes "work hardened" specimens, with a negative "true" LBS (many also with NDT=0%)

Table 9

EM Tester Based Estimates of Maximum Losses of Metallic Area (LMA_{max})

EM instrument		Mine	Mine-shaft rope			LMA_{max}	Tested		Our rope
type	operator[♣]		Constr.	Date on:	Date off:	(%)[†]	How	When	item No.
LMA-250	(6)	Noranda, Matagami Lake, Que.	$\frac{7}{8}$ in. 1 × 90 LC #2 H.R.;	29/11/87	in use	6.6	in situ	15/3/89	13
Rotescograph	(3)					4.5	in situ	15/3/89	
Magnograph	(4)					5.0	in situ	14/3/89	
LMA-250	(6)		as above #3 H.R.			10.6	in situ	15/3/89	14
Rotescograph	(3)					3.5	in situ	15/3/89	
Magnograph	(4)					7.5	in situ	14/3/89	
Rotesco AC	(2)	INCO, Sudbury, Ont. Shebandowan	$1\frac{3}{16}$ in. 1 × 136 LC #3 H.R.; (cage)	12/6/78	17/9/88[††]	3.0[**]	in situ	26/5/88	3
Rotesco AC	(2)					1.4	reel-to-reel	3/4/89	
LMA-250	(6)					1.6	reel-to-reel	4/4/89	
Magnograph	(4)					1.5	reel-to-reel	4/4/89	
Rotescograph	(3)					—	reel-to-reel	5/4/89	
Rotescograph	(3)					0.0	reel-to-reel	10/4/89	
Rotesco AC	(1)	Denison-Potacan, Sussex, N.B.	$1\frac{3}{16}$ in. 1 × 148 LC #3 H.R.	15/4/87	20/10/88	6.9[**]	in situ	15/3/89	4
Magnograph	(4)					10.5	in situ	15/3/89	
LMA-250	(5)					23.0	in situ	14/3/89	
Rotesco AC	(2)					5.4	reel-to-reel	15/3/89	
Magnograph	(4)					8.5	reel-to-reel	15/3/89	
LMA-250	(6)					10.8	reel-to-reel	14/3/89	
Rotescograph	(3)					—	reel-to-reel	10/4/89	
Rotescograph	(3)					9.0	reel-to-reel	10/4/89	

Table 9 (continued)

EM Tester Based Estimates of Maximum Losses of Metallic Area (LMA_{max})

EM instrument		Mine	Mine-shaft rope			LMA_{max}	Tested		Our rope item No.
type	operator♣		Constr.	Date on:	Date off:	(%)†	How	When	
Rotesco AC	(1)	Potash Co. of America, Sussex, N.B.	$1\frac{9}{16}$ in. 1 × 176 LC	4/8/87	24/11/88	4.5**	in situ	29/9/88	5
LMA-250	(5)					11.0	in situ	21/10/88	
Magnograph	(4)					9.0	in situ	20/10/88	
Rotesco AC	(2)					7.4	reel-to-reel	3/4/89	
LMA-250	(6)					15.0	reel-to-reel	4/4/89	
Magnograph	(4)					11.0	reel-to-reel	4/4/89	
Rotescograph	(3)					—	reel-to-reel	5/4/89	
Rotescograph	(3)					10.0	reel-to-reel	10/4/89	
Rotesco AC	(2)	INCO, Sudbury, Ont., Shebandowan mine	$1\frac{7}{16}$ in. 1 × 176 LC #3 H.R.; (skip)	12/6/78	17/9/88††	2.0**	in situ	26/5/88	6
Rotesco AC	(2)					2.0	reel-to-reel	3/4/89	
LMA-250	(6)					1.6	reel-to-reel	4/4/89	
Magnograph	(4)					1.5	reel-to-reel	4/4/89	
Rotescograph	(3)					—	reel-to-reel	5/4/89	
Rotescograph	(3)					0.8	reel-to-reel	10/4/89	
Rotescograph	(1)	First Canadian, Val d'Or, Que., Ressources AUR	1.000 in. 18 × 7 NR✓	—	late 1988	4.0**	in situ	15/9/88	1
LMA-250	(5)					4.8	in situ	9/9/88	
Magnograph	(4)					4.5	in situ	9/9/88	
Rotesco AC	(2)					4.2	reel-to-reel	3/4/89	
LMA-250	(6)		1.000 in. 6 × 27 STR✓			7.9	reel-to-reel	4/4/89	
Magnograph	(4)					5.5	reel-to-reel	4/4/89	
Rotescograph	(3)					3.6	reel-to-reel	10/4/89	

Table 9 (continued)

EM Tester Based Estimates of Maximum Losses of Metallic Area (LMA_{max})

EM instrument		Mine	Mine-shaft rope			LMA_{max}	Tested		Our rope item No.
type	operator♣		Constr.	Date on:	Date off:	(%)†	How	When	
Rotesco AC	(2)	INCO, Sudbury, Ont., Shebandown mine	$1\frac{4}{8}$ in. 18 × 7 NR #1 T.R. (skip)	6/2/81	5/9/88††	1.2**	in situ	26/5/88	8
Rotesco AC	(2)					0.8	reel-to-reel**	3/4/89	
LMA-250	(6)					0.4	reel-to-reel**	4/4/89	
Magnograph	(4)					0.5	reel-to-reel**	4/4/89	
Rotescograph	(3)					0.0	reel-to-reel	5/4/89	
Rotescograph	(3)					0.5**	reel-to-reel	10/4/89	
Rotesco AC	(1)	Potash Co. of America, Sussex, N.B.	$1\frac{7}{8}$ in. 34 × 7 NR	9/3/88	in use	2.0**	in situ	21/3/89	12
LMA-250	(5)					2.1	in situ	21/10/88	
Magnograph	(4)					8.0	in situ	19/10/88	
Rotesco AC	(1)	Denison-Potacan, Sussex, N.B.	$2\frac{1}{8}$in. (nominal)✓ $1\frac{7}{8}$in. (actual)✓ 34 × 7 NR #7 T.R.	7/6/85	15/12/88	17.6**	in situ✓✓	3/10/88	9
Rotesco AC	(2)					17.0	reel-to-reel	17/3/89	
Rotesco AC	(2)					17.0	reel-to-reel	3/4/89	
LMA-250	(6)					23.3	reel-to-reel	17/3/89	
LMA-250	(6)					23.5	reel-to-reel	4/4/89	
Magnograph	(4)					20.0	reel-to-reel	5/4/89	
Rotescograph	(3)					14.0	reel-to-reel	17/3/89	
Rotescograph	(3)					12.5	reel-to-reel	5/4/89	
Rotescograph	(3)					11.5	reel-to-reel	10/4/89	

Table 9 (continued)

EM Tester Based Estimates of Maximum Losses of Metallic Area (LMA_{max})

EM instrument		Mine	Mine-shaft rope			LMA_{max}	Tested		Our rope
type	operator[♣]		Constr.	Date on:	Date off:	(%)[†]	How	When	item No.
Magnograph	(4)	Thetford Mines, Que.,	$2\frac{1}{4}$ in.			5.0	in situ	15/4/89	
LMA-250	(6)	Bell mine,	34 × 7 NR	26/10/86	in use	3.5	in situ	7/4/89	11
Rotescograph	(3)	#3 shaft	#2 T.R.			3.4	in situ	7/4/89	
Rotesco AC	(1)					2.9**	in situ	21/4/88	
LMA-250	(6)	Les Mines CAMCHIB,	1.000 in.			4.9	reel-to-reel	4/4/89	
Rotesco AC	(2)	Chibougamau,	6 × 27 FS	12/5/80	September, 1988	3.8	reel-to-reel	3/4/89	2
Magnograph	(4)	Que.,				4.0	reel-to-reel	4/4/89	
Rotescograph	(3)					—	reel-to-reel	5/4/89	
Rotescograph	(3)					2.6	reel-to-reel	10/4/89	
Magnograph	(4)					11.5	in situ	23/8/88	
LMA-250	(5)					12.0	in situ	9/9/88	
Rotescograph	(1)					11.0**	in situ	9/9/88	
Rotesco AC	(1)	Minerais LAC,				8.4**	in situ	9/9/88	
Rotesco AC	(2)	la mine Doyon,	$1\frac{1}{2}$in.	7/2/87	late 1988	13.0	reel-to-reel	3/4/88	7
LMA-250	(6)	Rouyn,	6 × 30 FS			12.0	reel-to-reel	18/1/89	
LMA-250	(6)	Que.				17.0	reel-to-reel	4/4/89	
Magnograph	(4)					11.5	reel-to-reel	18/1/89	
Magnograph	(4)					13.5	reel-to-reel	5/4/89	
Rotescograph	(3)					—	reel-to-reel	5/4/89	
Rotescograph	(3)					7.6	reel-to-reel	10/4/89	

Table 9 (continued)

EM Tester Based Estimates of Maximum Losses of Metallic Area (LMA_{max})

EM instrument		Mine	Mine-shaft rope			LMA_{max}	Tested		Our rope
type	operator♣		Constr.	Date on:	Date off:	(%)†	How	When	item No.
Rotesco AC	(2)	INCO, Sudbury, Ont., Frood mine	$1\frac{3}{4}$ in. 6 × 25 R.S.	2/3/87	24/10/88	5.7••	in situ	26/9/88	10
LMA-250	(6)					7.6	reel-to-reel	4/4/89	
Magnograph	(4)					5.5	reel-to-reel	4/4/89	
Rotescograph	(3)					5.0	reel-to-reel	4/4/89	
Rotescograph	(3)					—	reel-to-reel	4/4/89	
LMA-250	(6)	Own Test-rope with artificial defects	$1\frac{3}{4}$ in. 6 × 27 F.S. No.1 rope	4/4/89	in use	8.2	reel-to-reel	4/4/89	15
Magnograph	(4)					7.0	reel-to-reel	4/4/89	
Rotescograph	(3)					5.0	reel-to-reel	5/4/89	
LMA-250	(6)		as above No. 2 rope			6.5	reel-to-reel	4/4/89	16
Magnograph	(4)					7.5	reel-to-reel	4/4/89	
Rotescograph	(3)					6.4	reel-to-reel	10/4/89	

♣: (1) = from instr. maker cum service co.; (2) and (3) = from mining co.; (4) and (5) = from service co.; (6) = from govt. agency.

†: as reported by instrument operator.

••: authors' LMA estimate, based on instrument chart; instr. operator only reported LBS.

††: mine was shut down from 1985 to 1988, with ropes left in situ.

**: only a 395 ft length of the entire 2100 ft tail-rope was tested reel-to-reel. Latter was part of the rope's loop section in situ, and, therefore, considered to be the ropes's worst section. Whole rope length tested in situ.

√: these inconsistencies need to be clarified.

√√: only 400 ft of entire 3000 ft rope-length tested reel-to-reel. Whole rope-length tested in situ.

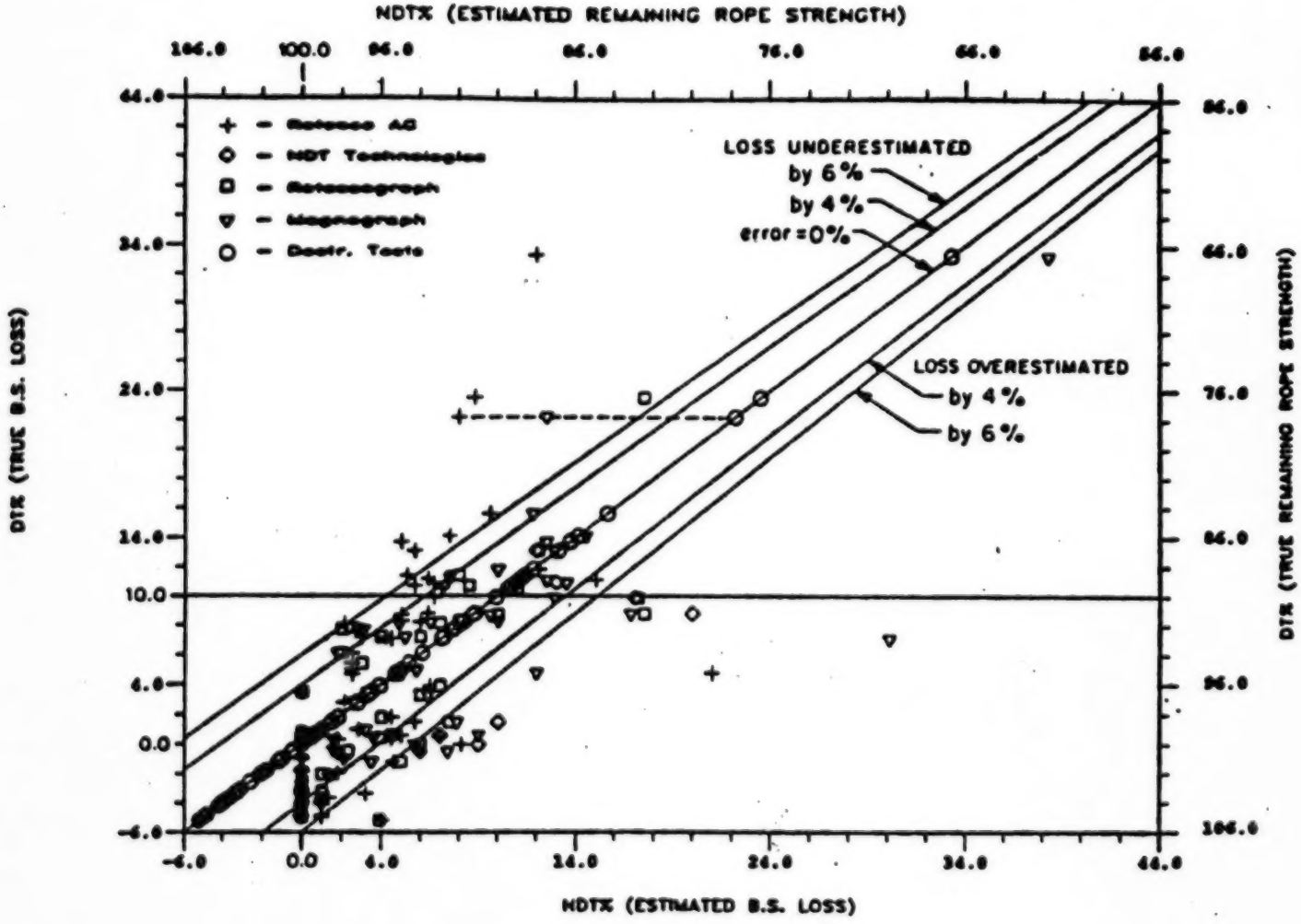

Fig.1 — Locked coil ropes; all comparative test data

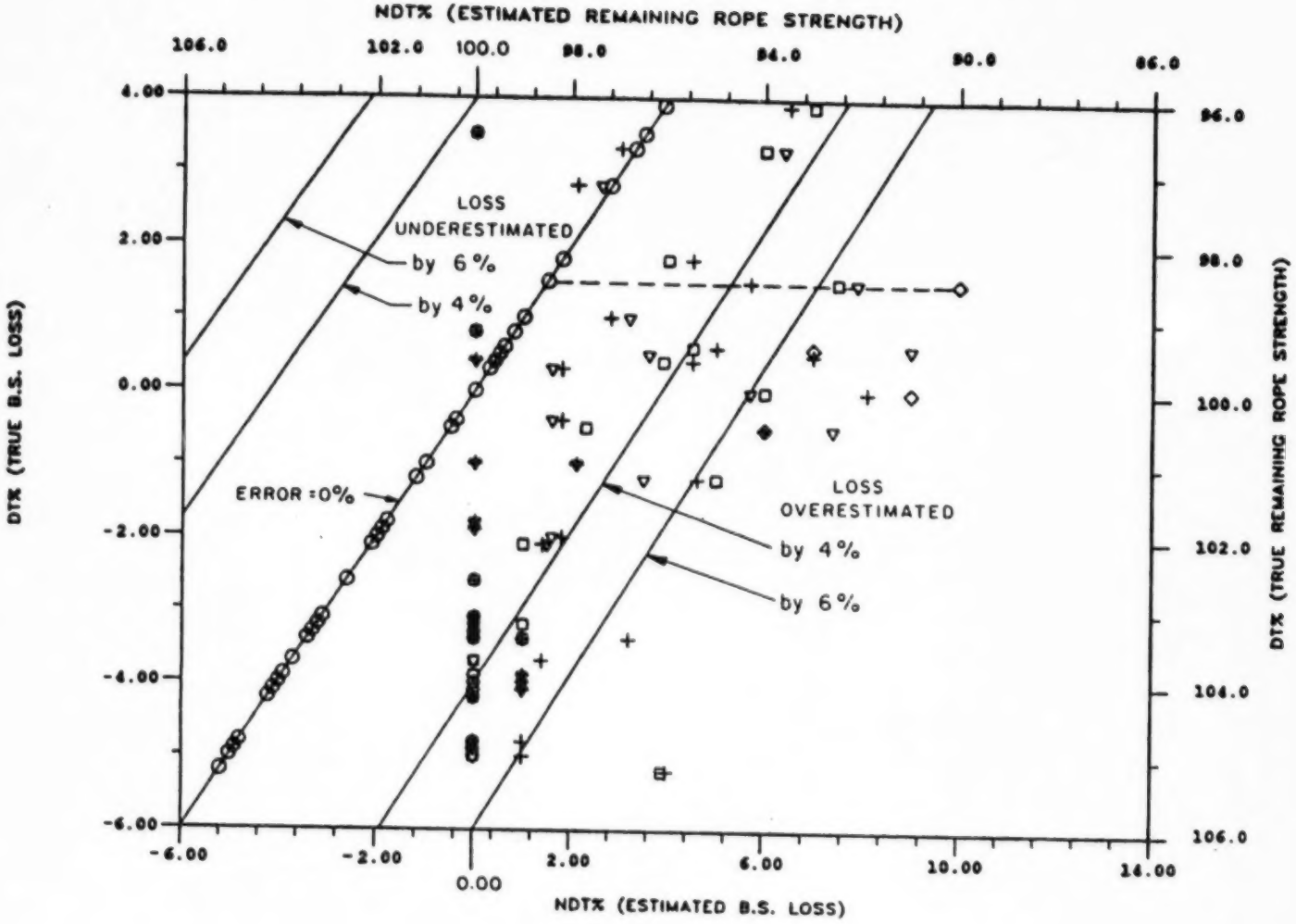

Fig.1a — Locked coil ropes; – 6% to 4.0% "true" LBS range

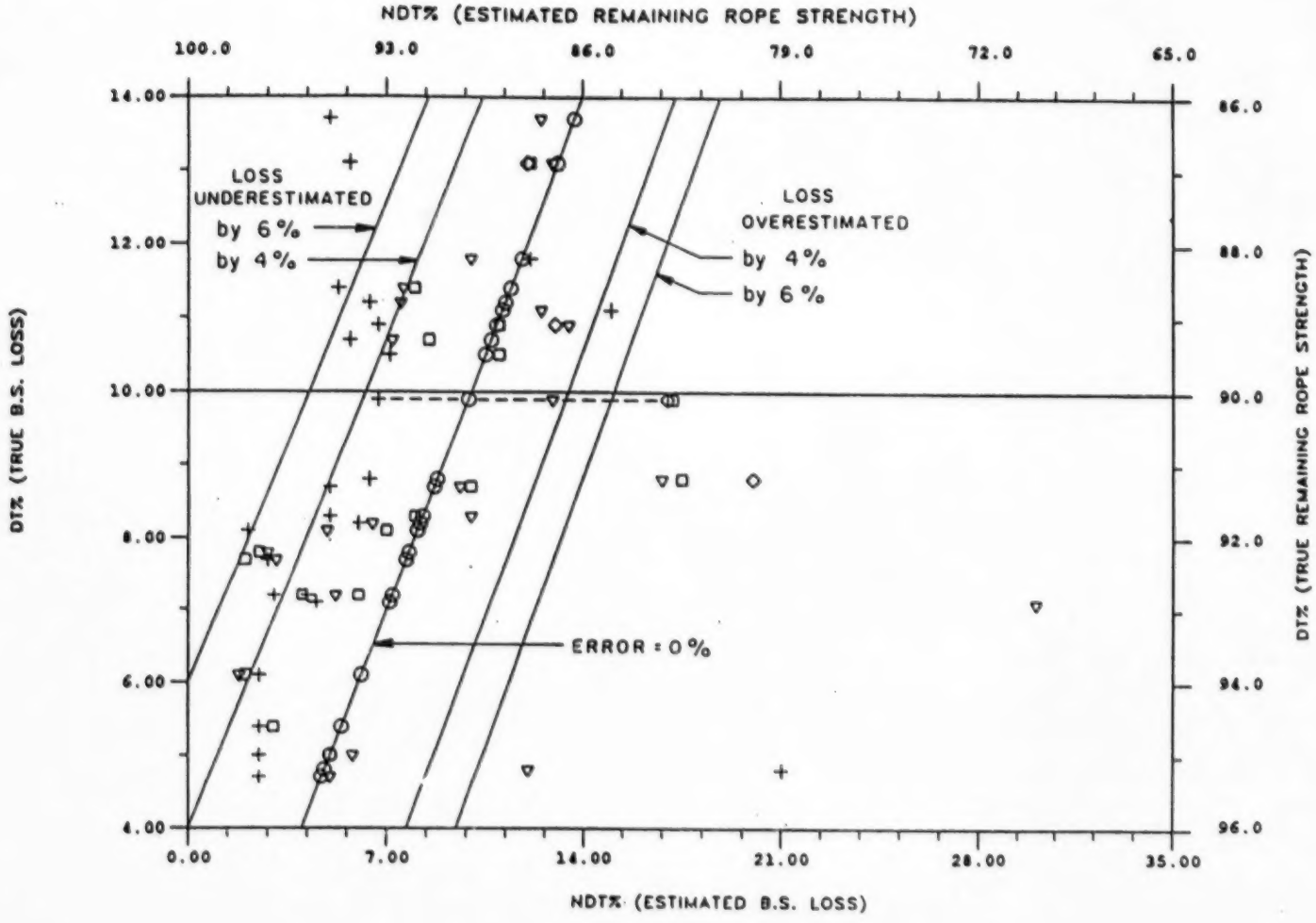

Fig.1b — Locked coil ropes; 4.0% to 14.0% "true" LBS range

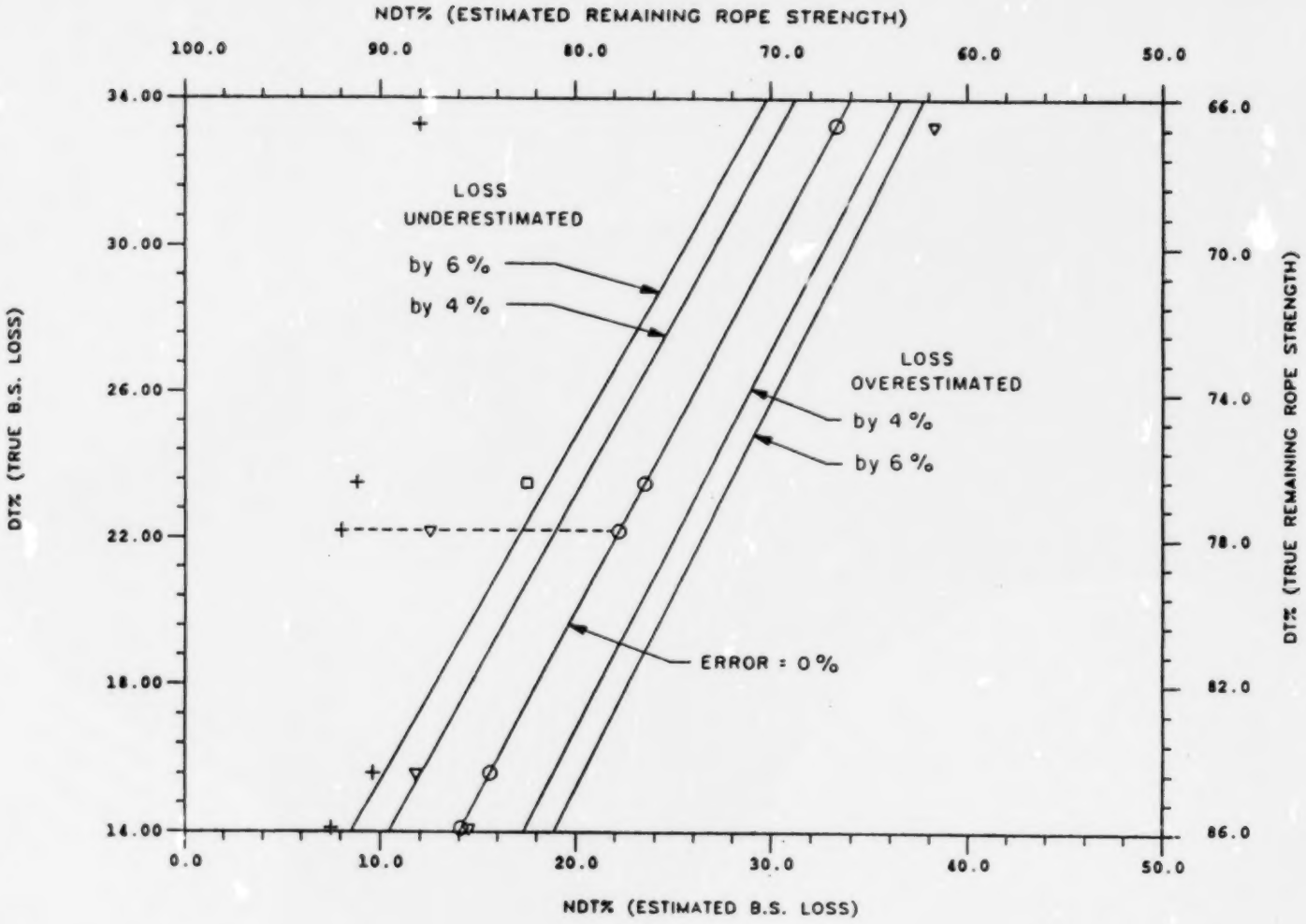

Fig.1c — Locked coil ropes; 14.0% to 34% "true" LBS range

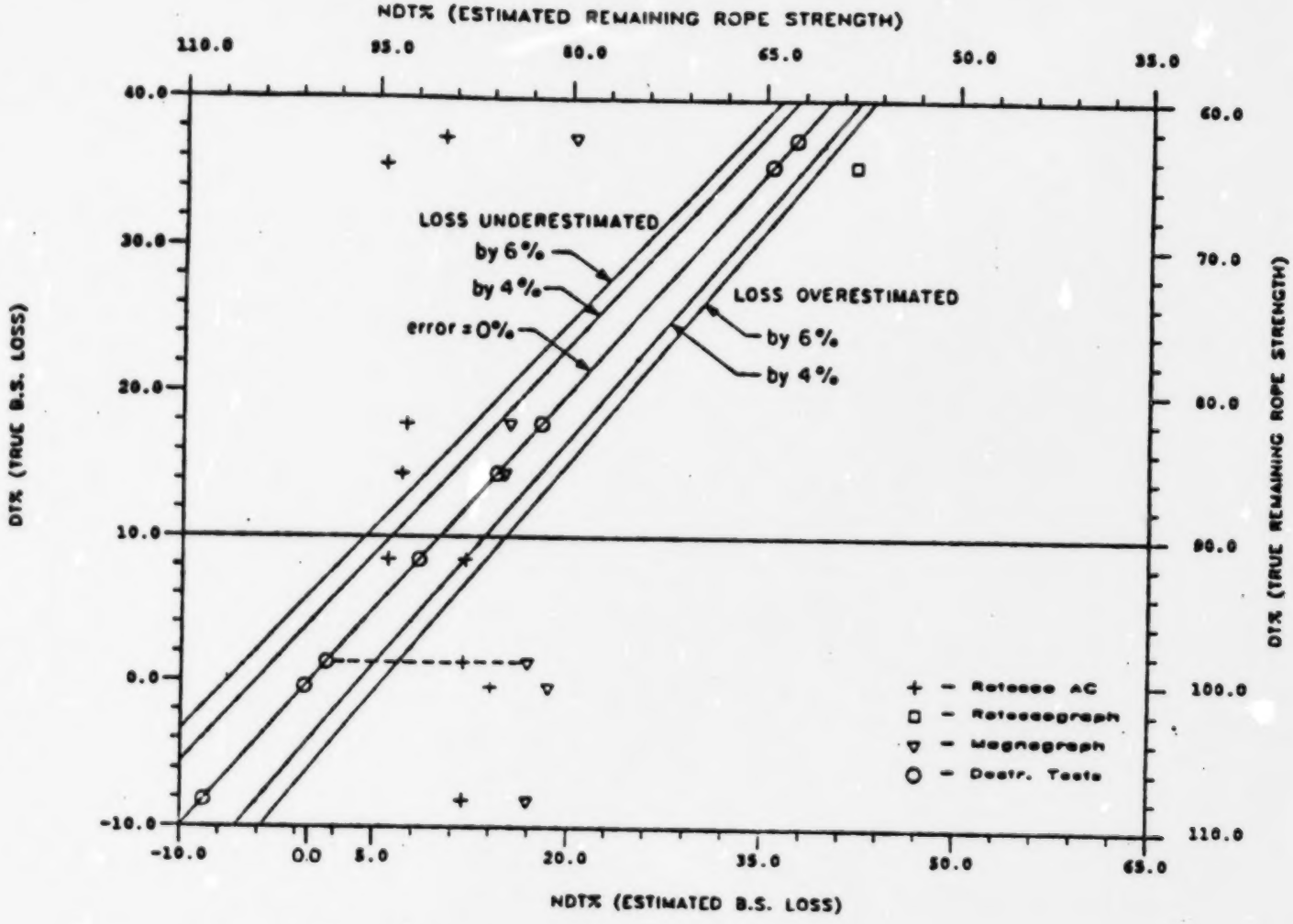

Fig.2 — Non rotating ropes; all comparative test data

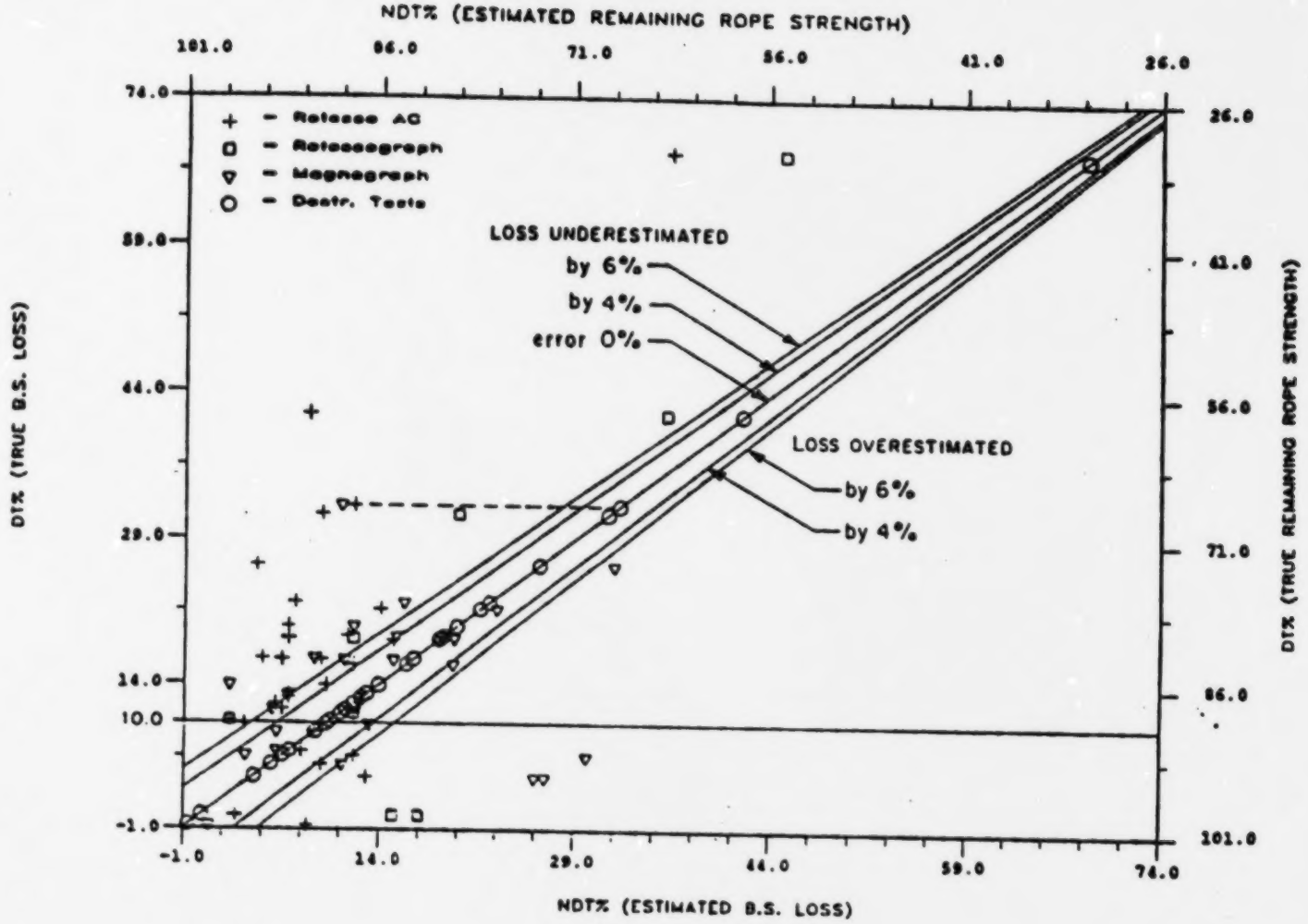

Fig.3 — Stranded ropes; all comparative test data

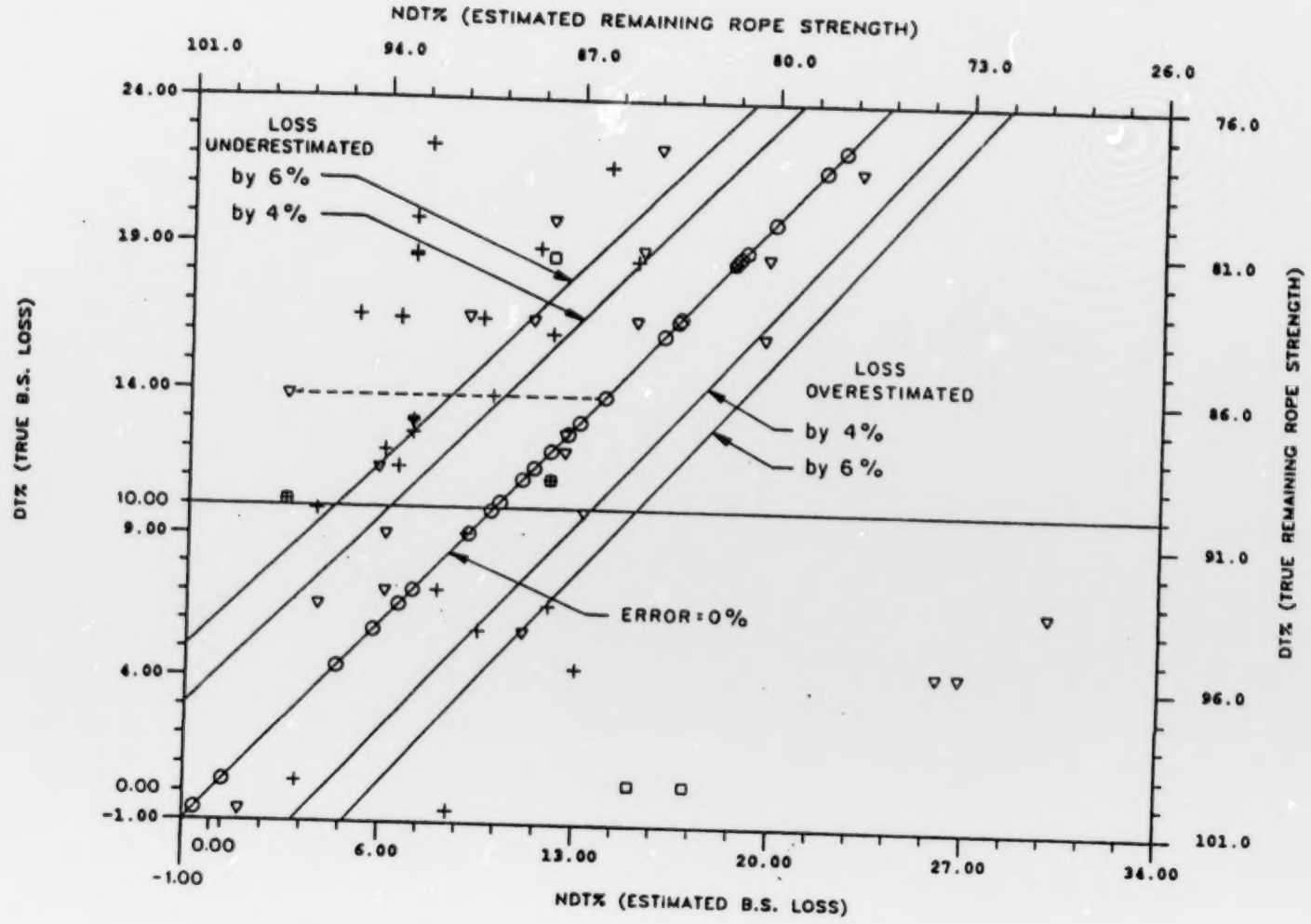

Fig.3a — Stranded ropes; – 1.0% to 24.0% "true" LBS range